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POST GRADUATE STUDIES IN ROAD AND TRANSPORT ENGINEERING

ANALYSIS OF LAND USE AND TRANSPORTATION DEMAND INTERACTIONS IN ADDIS ABABA
(A CASE STUDY: AKAKI KALITY SUB CITY)

A thesis submitted to the School of Graduate Studies of the Addis Ababa Science and Technology University in Partial fulfillment for the Degree of Masters of Science in Civil Engineering under Road and Transport Engineering.

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I hereby declare that the thesis entitled "Analysis of Land use and transportation demand interactions in Addis Ababa (Case study: Akaki Kality sub city" has been carried out by me under the supervision of Dr. Alemayehu Ambo, Addis Ababa Science and Technology University, Addis Ababa during the year 2017-2018 for the partial fulfillment of the requirements for the Degree of Master of Science in Road and Transport Engineering.

I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma; and that all the sources of the materials used in the thesis have been accordingly acknowledged.

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C E R T I F I C A T E

This is to certify that the thesis entitled “Analysis of Land use and Transportation Demand Interactions in Addis Ababa (Case study: Akaki Kality sub city” is an authentic work carried out by Belsti Asres Gebrehana under my guidance and supervision. This is the actual work done by Belsti Asres for the partial fulfillment of the requirements for the Degree of Master of Science in Road and Transportation Engineering from Addis Ababa Science and Technology University, Addis Ababa.

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Dedication

Dedicated to my beloved father; Kess Asres Gebrehana who tragically died of car accident on March 9, 2018.

ABSTRACT

Nowadays, the provision of appropriate transportation infrastructure and integrated mobility services in the Ethiopian cities, especially in Addis Ababa, is a problem to vehicle operators, the public and the Government in respect of costs, environment and traffic accidents. Specifically, planning transportation infrastructures and integration with land use and coverage of area is a major concern.

This research analyzes the land use and transportation demand interaction in Addis Ababa considering the Akaki Kality Sub City as a Case Study. Transportation demand analysis in conjunction with studying the extents of urban expansion along with land use pattern changes and analysis on interactions of the two were the major undertakings that were dealt with in the study. It assessed and analyzed the continual day-to-day increment of public transportation demands and transportation problems due to high variability of land use change and high rate of urban expansion that are taking place around the peripheral of the Addis Ababa City.

The four step transportation demand model was utilized in the study to analyze the present and future land use patterns of the city, Satellite image classification along with analyzing the change of land use for the past twenty-nine (29) years were performed. To carry out the study successfully; primary, secondary, and tertiary data were collected. In analyzing the spatial data, the Arc GIS 10.1 software was utilized. Similarly, statistical, mathematical, and graphical analysis was dealt with. To make the research specific and effective, six major destinations of the Akaki Kality sub-city passengers were selected and dealt with.

By analyzing the data, adopting different equations, models, and calibrate parameters; it was found that the population of the Addis Ababa city has been growing by 3.8% yearly while the physical built up area has been correspondingly increasing by 3.2%. On the other hand, due to high economic growth and people's interest in owning private cars, the number of vehicles has been increasing by 13.5% yearly causing the yearly average urban mobility increment by 10 %. However, the road network coverage has grown only by an average of 4.1% per year which cannot accommodate the increasing transportation demand and vehicle fleets. This results in continual day-to-day transportation and social problems of the city like congestion, traffic accidents and environmental impacts.

Finally the research has identified possible short- and long- term solutions including the promotion of mass transportation system for solving future pertinent problems giving directions for potential researches related to this topic.

Key words: Addis Ababa city, Akaki Kality sub-city, Land use, Zoning, Transportation, GIS,

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LIST OF ABBREVIATIONS

AACATA: Addis Ababa City Administration Transport Authority
AACRA: Addis Ababa City Road Authority
AACRTB: Addis Ababa city Road Transport Bureau.
AALRT: Addis Ababa Light Rail Transit
AU: African Union
BRT: Bus Rapid Transit
CSA: Central Statistics Agency
ERA: Ethiopian Road Authority
ERTRAC: European Road Transport Research Advisory Council
FSTM: Four step transportation demand modeling
GDP: Growth Domestic Product
GIS: Geographical information system
HBE: Home Based Education Trip
HBO: Home Based Other Trip
LOS: Level of Service
LULC: Land Use Land Cover
LUTI: Land Use and Transport Interactions
NHB; Non Home Based Trip
O-D: Origin Destination
PCE: Passenger Car Equivalence
TAZ: Traffic Analysis Zone
TfGM: Transport for Great Manchester.
UN: United Nation
UTS: Urban Transport Study

CHAPTER ONE

1. INTRODUCTION

1.1. General

Transportation is the movement of peoples, goods, or services from one particular location to another through communication media (transport infrastructures) by using motorized or non-motorized vehicles.

The movement of people and goods in a city, referred to as traffic flow, is the joint consequence of land activity (demand) and the capability of the transportation system to handle this traffic flow (supply). Hu Peng and Huapu Lu (2007) Suggests Transportation planning and land-use relates to two main aspects: general spatial and land-use patterns that have an impact on transportation volumes and the spatial/land-use requirements of transport infrastructure.

According to the United Nations Population Division, World Urbanization Prospects (1999); in 1950, only 18% of people in developing countries lived in cities. In 2000, the proportion was 40% and in 2030 the developing world will be 56% urban. On the other hand in 2000, the developed world was estimated at 76% urban. This shows that developing countries have much faster urban population growth with an average annual growth rate of 2.3%, compared to the developed world's urban growth rate of 0.4%. Rapid urban growth in developing countries reflects substantial migration to cities from rural areas and natural population increase among city residents which is currently the case in Addis Ababa. Among developing countries, an estimated 60% of urban growth during 1960-1990 was from natural increase 40% from in-migration from rural areas and the expansion of urban boundaries.

Transportation system and land use plans are interrelated activities and these entities perform in co-ordination for effectiveness and sustainability. Transportation has impacts on economic development and an economic system has an impact over transportation systems. In other words, transportation supply and demand are mutually interdependent. Zhao et al (2003) states ‘The construction of a highway interchange favors the emergence of a commercial center, which will generate supplementary transportation demand, which in turn will favor the location of new activities and a re-organization of the regional spatial structure.’

Land use analysis includes different spatial scopes: like local at the level of a municipality, urban at level of cities and towns, regional at level of districts, national at level of countries and even that is observed with regard to land use and transport interaction, The land uses type, such as residential, industrial, commercial, or free land on the urban area shows the situations of human activities such as living, working, shopping, education or leisure; and human activities requires connections or transportation services that leads to trips in the traffic system crossing places between the locations of activities. To pass across this distance within specified time limit, transportation infrastructures are needed. The distribution of transportation infrastructures in the system creates opportunities for different human activities on areas like; settlement, planting industries and factories, and to build other service sectors (schools, health centers, commercial centers, institutions etc.) and so results in changes of the land-use system. Bannister and Berechman (2000) said 'Transportation influences the amount of land available for development and the spatial distribution of economic activity. In turn, this has an impact on land prices, housing affordability, business costs, productivity and, ultimately, economic performance. At a finer level, a transportation infrastructure has an impact on the quality of urban realm, and, indirectly, on the economic use which is made of different places. Urban areas require transport infrastructure to function, with transportation generating values by enabling some of the most productive land uses and often the highest land value.'

Shoup (1997) concludes 'When transportation is not implemented efficiently, valuable land can be taken up by activities that do not generate value; for example, free parking. By linking transportation and land use, it is possible to make urban areas more efficient, enabling denser and more productive economies to develop'. 'Transportation infrastructure determines how many people can get to a location using a given amount of space and set infrastructure, with some modes of transportation capable of delivering greater benefits more efficiently' (Bannister, 2002).

1.2. Statement of the problem

The basic problems which are observed in the transportation system in Addis Ababa in general and in Akaki Kality sub city in particular are the followings:

- The continual day-to-day increment of transportation users shows that there is high growth rates of urban land use change and urban expansion;
- The longest queue formed by passengers at some taxi stations (e.g. Akaki, Kality Total Fuel Station and Kality Gebriel) at peak hour shows that there is insufficient availability of transportation services resulting in more waiting times and hence delay from planned time of activities; and
- The variability of travel costs and limited frequencies in transportation modes may show that as there is delay and congestion due to the absence of adequate and integrated road infrastructures in the city. Hence the road network going to fail to accommodate the increasing travel demands requirements.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this research is to analyze the land use and transportation interaction and also to study the transportation demand in Akaki Kality Sub-City which is within the city of Addis Ababa and to come up with possible solutions for existing and future problems.

1.3.2. Specific objectives

The Specific objectives of this study are to:

- Study the transportation demand of Akaki Kality Sub-City using the four step transportation demand model (FSTM): trip generation, trip distribution, modal split, and traffic assignment;
- analyze the present and future land use pattern of the Sub-City by performing image classification and studying the type of urban expansion; and
- assess the interactions of land use and transportation demand.

1.4. Research questions

- May transportation problem be directly related to the type of urban expansion which takes place in fast growth?
- Why the four step transportation demand modeling be adopted in studying travel demand and expansion of urban infrastructural service, especially road infrastructure?
- By how much should the transportation demand grow from year to year and by how much should it function in providing optimum service for passengers?

1.5. Significance of the study

- This research may put some solutions for different transportation system problems in Addis Ababa, specifically in Akaki Kality sub city.
- The research will help to forecast the future transportation demands and infrastructural service requirements based on the current situations of the study area by using different engineering techniques.
- To adopt equations, models and software simulations to calibrate parameters, constants, and adjustment factors.
- This study will likely contribute to additional insights, perspectives, and generates firsthand information on the study area for those who are interested to conduct further researches regarding the issue.

1.6 Scope and limitation of the study

1.6.1 Scope of the study this research attempts to study the interdependencies between public transportation demand and urban land use changes within the peripherals of Addis Ababa city. To deal with this, the Akaki Kality sub city and its six trip destinations were selected to conduct public transportation demand analysis. The study forecasts the future transportation needs, estimate the numbers of vehicles and assess urban built up, land use change and expansions within the sub city for the year 2040 and put long term and short term solutions for public transportation demand problems.

1.6.2 Limitation of the study Due to data unavailability, the research dealt with only on public transportation demand. On the other hand, intensive door-to-door surveys for socio-economic data collection for use in transportation demand study was found to be time and resource consuming. Accordingly, secondary data were used from previous studies and respondent sectors. This made the study more descriptive type. Figure 1 below illustrates the organization of the research report.

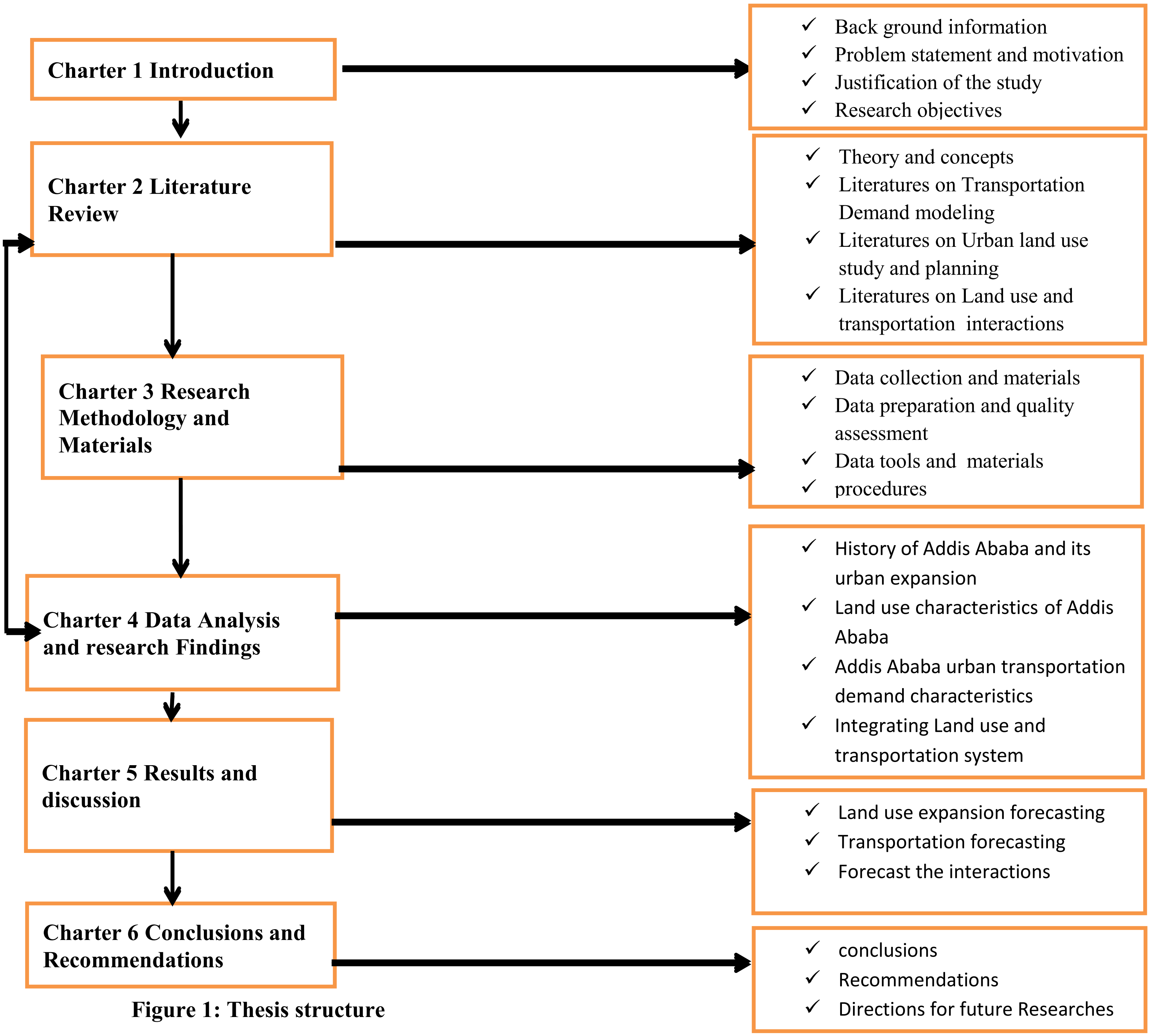


Figure 1: Thesis structure

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Transportation Demand Modeling

In a travel demand model, traffic volumes are forecast through the interaction of transportation supply and demand. Traffic zones are areas that represent demand, while the actual road network and vehicles represents supply. The four step travel demand modeling was developed in the 1950's and 1960's. Four decisions are the basis of the traditional travel demand model. These decisions are: the choice and reasons to travel (trip generation), the destination to travel (trip distribution), the mode by which to travel (modal choice), and the route on which to travel (trip assignment). These four decisions are arranged according to what each to respond for the trips information and related evidences,

2.1.1. Trip Generation

Trip Generation is the first step in the four-step transportation forecasting process, which is used for forecasting travel demands. It is the method of prediction of the number of trips made by passengers for a particular traffic analysis zone. The trips may be either from or to the traffic analysis zone. In this regard, the first part is determining how many trips are originated in a zone and the second part is how many trips are destined for a zone.

'The objective of trip generation modeling is to develop an expression that predicts exactly when a trip is to be made. This is an inherently difficult task due to the wide variety of trip types (working, social/recreational, shopping, etc.) and activities (eating, exercising, visiting friends, etc.) undertaken by a traveler in a sample day'(Fred and Scott, 2013).

So, trip generation is the process of estimating the number of trips that will begin or end in each zone within the study area. The amount of traffic generated can be related to different characteristics that are related to trip making, for instance characteristics of trip-makers (e.g. age, income, car ownership, household size, etc.), and characteristics of developments (e.g. number of units, square footage of floor area, number of parking space, etc.).

The principal task of trip generation is to relate the intensity of trip making to and from land use parcels to measure the type and intensity of land use. There are two types of trip analysis that are normally carried out; these are trip production analysis and trip attraction analysis.

2.1.1.1. Trip production Analysis

The term trip production refers to the trips generated by residential zones, where these trips may be trip origins or trip destinations. According to report from the National Cooperative Highway Research Program, 2012, the trip which is produced from specific zone may be homing based or non-home based, according to the origins and destinations of trips and reasons for trips. Home based trips are those trips which have one trip end at household; example: work trip, educational trip, shopping trip, and personal business trips. But non-home base trips are trips between work place and shopping area, business trips between two activity centers, etc.

Trip production modeling is the process of relating the trips produced by households to the factors of influencing trip production by appropriate analytical technique. Most of the influencing factors are the followings; household size and compositions, number of employed persons in a household, number of students in a household, household income, vehicle ownership etc. Most of the time, regression analysis is used to relate the dependent variable (trip production) to the set of influencing factors (independent variables).

2.1.1.2. Trip Attraction Analysis

The term trip attraction is used to describe trips generated by activities at non-home end of trips. It depends on land use characteristics. For instance, the common types of land uses are: residential, commercial, industrial, institutional, recreational, etc. 'The factors influencing trip attractions are: retail trade floor area, service and office floor area, manufacturing and whole floor area, number of employment opportunities in retail trade, school and college enrolment, number of special activity centers (transport terminals, recreational places, sport stadium, religious places) etc.' (Fred and Scott, 2013).

2.1.2. Trip Distribution

'In the traditional four-step transportation forecasting model, trip distribution studies about trip makers' origins and destinations to develop a "trip table", which is a matrix that displays the number of trips going from each origin to each destination. This means trip distribution is zonal interchange analysis that produces a set of origin-destination tables which tells where the trips will be made' (Ortuzar & Willumsen, 2004).

Trip distribution requires explanatory variables that are related to the impedance (generally a function of travel time and/or cost) of travel between zones, as well as the amount of trip-making activity in both the origin zone and the destination zone. The inputs to trip distribution models include the trip generation outputs, the productions and attractions by trip purpose for each zone and measures of travel impedance (generalized cost of travel between two zones. In most cases, travel time is often expressed in minutes between each pair of zones, obtained from the transportation networks). Socio-economic and area characteristics are sometimes also used as inputs. The outputs are trip tables illustrating production zone to attraction zone by each trip purpose. 'Because trips of different purposes have different levels of sensitivity to travel time and cost, trip distribution is applied separately for each trip purpose, with different model parameters. In this regard, the gravity model is the most common type of trip distribution model used in four-step models.'(Quade & Douglas, 1994).

2.1.3. Modal Split Analysis

Modal split analysis is the third step in the conventional four-step transportation forecasting model. Mode choice analysis allows the modeler to determine what mode of transportation will be used. 'Mode choice of traveler involves a specific aspect of human behavior dedicated to choice decisions. With a model, simplified representation of a part of reality provides a better understanding and interpreting of these complex systems' (Ortuzar & Willumsen, 2004). There are many different types of models that have been developed to simulate actual travel patterns of people and existing demand conditions

'Traditionally, aggregate models are used in dealing with the travel choice behavior of individual travelers. However, the aggregate models have the limitation of forecasting and estimating of travel choice with aggregated zonal data . Due to this reason, the most widely used method of mode choice is using disaggregate approach which is based on 'discrete choice theory' or 'random utility theory.' (Ortuzar & Willumsen, 2004). 'The factors for traveler's choices to use which type of mode to use are: travel time, travel cost, travel comfort, economic status of travelers, accessibility of modes, and traveler's safety in which each of them to be translated into monetary value' (Horowitz et al, 1986).

2.1.4. Traffic Assignment

Traffic Assignment is the fourth step in the conventional transportation forecasting model. The concerns on the selection of routes (alternative called paths) between origins and destinations in transportation networks are: to determine facility needs and costs and benefits, to know the number of travelers on each route and link of the network (a route is simply a chain of links between an origin and destination).

The major purpose of the traffic assignment process is to show the pattern of vehicular movements on the transportation system. This process is concerned with the trip maker's choice of path between pairs of zones by travel mode and with the resulting of vehicular flows on the transportation networks. The number of available paths between any pairs of zones depends on the mode of travel. So the objective of knowing traffic volume on the links within the network enables to estimate travel costs, total distance covered by the vehicle, total system travel time, zone-to-zone travel costs (times) and to identify heavily congested links.

In the case of private transportation modes, there are a lot of path possibilities for using and have good deal of freedom in selecting them. However, on the other hand in some mass transit modes, there may be limited number of paths to be followed.

According to Ortuzar & Willum (2001), there are a number of factors that are contributed for the choice of a route when driving between two points; thus include travel time, travel distance, travel cost including fuels, congestion, and queues, type of road, sign postings, road works, etc.. However, to incorporate all as generalized cost is a difficult task, and so some approximations are inevitable. The most common approximation is to consider only two factors: time and monetary cost in route choice; monetary cost is proportional to travel distance. Thus the weighted sum of these two factor values become generalized cost used in estimating route choice.

There are different types of traffic assignment models which are developed and used most commonly; such as: All-or-nothing assignment; STOCH assignment; Incremental assignment;

Capacity Restraint assignment; User Equilibrium assignment (UE); Stochastic User Equilibrium assignment (SUE), and System Optimum assignment (SO), etc.

2.1.5. Summary of four step travel demand modeling

In the four step travel demand modeling process, Trip Generation answers how many trips will be generated by a given location and when will these trips made, Trip Distribution answers what are the origins and destinations of these trips, Modal Choice answers which mode of transportation will be used to make the trip, and Traffic Assignment responds for which route on the transportation network will be used when making the trip.

The interaction among traffic zones occurs because each zone produces and attracts person trips. Information contained within each zone (such as; population, households, and employment) determines the amount of trips produced and attracted. Households are the primary producer of trips, while employment sites are the primary trip attractors. These productions and attractions are converted to vehicle trips that enter and leave each zone. The fact that people make trips for different purposes (work, shopping, school, personal business, recreation, etc.) - and have different vehicle occupancy rates in doing so - is also calculated into the model. This entire process is called trip generation.

‘The process of trip distribution determines where the trips end up once they leave their traffic zones. Trip distribution produces a matrix of origins and destinations between all zones for each trip purpose. This is done according to the "attractiveness" of a zone, based on its proximity to other zones and on the total number of trips generated in that zone. Zones that are closest to each other will have more trips flowing between them, all other things being equal. The more trips a zone generates relative to all other zones, the greater the "pull" it will exert on all other zones in terms of attracting trips. This is the basic theory behind the gravity model, which is often used in travel demand forecasting.’ (Dr. John Douglas, 2005)

For all trips between zones, mode choice refers to the relative proportions that use each particular mode of transportation, mainly auto, transit, bicycle, walking, etc. This step can be fairly simplistic or very detailed, depending on the complexity of the network and the number of transportation options available in a given area. For example, “nested” models can account for a wider variety of mode choices, including whether people drive alone or carpool, and what specific type of transit they take (bus, subway, commuter rail, ferry). The mode choice step is often done through multiple iterations of trip distribution and assignment as part of a feedback loop. Trip assignment determines what route, or path, trips will take in going from zone to zone. This is where the travel demand of the traffic zones interacts with the supply, provided by the road and transit systems. All trips from all zones are assigned along the network to all their destination zones. From this point, there are several different methods of trip assignment. In one such method, each individual path is determined through factors such as minimum travel time (determined by the speed, capacity and intersection delays of the utilized links), and congestion that would arise from too many vehicles using a particular link or route. The end result produces traffic volumes for all roads in the network.

Once a model produces traffic volumes, it must be calibrated. Calibration refers to the adjusting of various model factors and components - and running the model again until it replicates current travel patterns and traffic volumes at acceptable levels of accuracy. Adjustments and subsequent model runs must often be conducted many times before acceptable results are reached. Once the model is calibrated to current conditions, it can then be used to forecast future scenarios. ‘Calibration of a travel demand model is often a continuing process in order to achieve results that are more accurate and to keep pace with changes in the latest planning assumptions and growth projections.’ (Ferdous et al, 2012).

2.2. Urban land use study and planning

Land cover is studied through environmental factors such as soil characteristics, climate, topography, and vegetation. The major determinants of land use are: demographic factors such as population size and density, technological advancements (such as the extension of basic transport infrastructure such as roads, railways, and airports), level of comfortable circumstances, political structures, and systems of ownership can open up previously inaccessible resources and lead to their exploitation and degradation.

According to the United Nations Population Division, World Urbanization Prospects (1999); in 1950 only, 18% of people in developing countries lived in cities. In 2000 the proportion was 40% and in 2030 the developing world will be 56% urban. On the other hand in 2000, the developed world population was estimated at 76% urban. This shows that developing countries have much faster urban population growth with an average annual growth rate of 2.3%, compared to the developed world's urban growth rate of 0.4%. Rapid urban growth in developing countries reflects substantial migration to cities from rural areas and natural population increase among city residents. Among developing countries, estimated 60% of urban growth in 1960-1990 was from natural increase, 40% from in-migration from rural areas and the expansion of urban boundaries.

The United Nations Food and Agriculture Organization Reports (1993) stated that land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances.

‘The land classification plan identifies areas where development will be encouraged (urban, transition, or development areas) and areas where development will be discouraged (open space, rural, conservation, or critical environmental areas). For each designated area, policies about the type, timing, and density of allowable development, extension of infrastructure, and development incentives or constraints apply. The planning principle is to concentrate financial resources, utilities, and services within a limited, pre- specified area suitable for development, and to relieve pressure on non-development areas by withholding facilities that accommodate growth’ (Edward, et al, 1995).

‘Urban expansion takes places in substantially different forms. In any given city, new urban expansion can take place with the same densities (persons per square kilometer) as those prevailing in existing built-up areas, with increased densities, or with reduced densities. It can take place through the redevelopment of built-up areas at higher densities, through infill of the remaining open spaces in already built-up areas, or through new “green field” development in areas previously in non-urban use. New green field development can either be contiguous with existing built-up areas or can “leapfrog” away from them, leaving swaths of undeveloped land that separate it from existing built-up areas. It can encroach upon wetlands, watersheds, forests, and other sensitive environments that need to be protected, as well as upon farms, fields, and plantations surrounding the city. and it can thus reduce, maintain or increase open space in and around the city' (Shlomo, ete'al, 2005).

Thus this research is going to study the physical urban expansions of Addis Ababa for the last years which has significant impact on travel demand increments from year to year.

2.3. Land Use and transportation interactions

Transportation influences the amount of land available for development and the spatial distribution of economic activity. In turn, this has an impact on land prices, housing affordability, business costs, productivity, and, ultimately, economic performance.

'By linking transportation and land use, it is possible to make urban areas more efficient, enabling denser more productive economies to develop. Transportation can also impact on the health and wellbeing of the population, in terms of air quality, safety, and levels of participation in work and training, and social interaction' (TfGM, 2013). By reducing the amount of space required to transport people, allowing for quicker journey times and making more space for leisure and more productive activities, transport infrastructure can transform urban environments, increasing the value that people attach to urban spaces. This presents a complex interdisciplinary challenge if the full value of transport schemes is to be understood and measured.

'Urban form is both shaped by transportation and determines travel patterns, with the efficiency and cost of transportation systems determining how urban areas develop. The interaction between transportation and wider areas of planning policy, such as housing, shapes the transportation options that are open to us and how we travel. Understanding this relationship is vital for urban function as not all forms of transport are equal, with some enabling more productive urban economies that are better for the environment and protect quality of life' (Cervero and Landis, 1995).

Land use can be divided into two broad categories: residential and non-residential. For the residential side of things, trip generation is thought of as a function of the social and economic attributes of households (households and housing units are very similar measures, but sometimes housing units have no households, and sometimes they contain multiple households, clearly housing units are easier to measure, and those are often used instead for models, it is important to be clear which assumption you are using). At the level of the traffic analysis zone, the language is that of land uses "producing" or attracting trips, where by assumption trips are "produced" by households and "attracted" to non-households. Productions and attractions differ from origins and destinations. Trips are produced by households even when they are returning home (that is, when the household is a destination).

‘The availability of transportation facilities can strongly influence the growth and development of a region or nation. Good transportation permits the specialization of industry or commerce, reduces costs for raw materials or manufactured goods, and increases competition between regions, thus resulting in reduced prices and greater choices for the consumers’ (Garber and Hole, 2009).

‘Travel demand and traffic forecasting is a formidable problem because it requires accurate regional economic forecasts as well as accurate forecast of highway users, social and behavioral attitudes regarding trip-oriented decisions, in order to predict growth / decline trends and traffic diversion’ (Mannering and Washburn, 2013).

An integrated research initiative on land use and transportation interactions (LUTI), done by the European Road Transport Research Advisory Council (ERTRAC) in June 2013, stated that ‘The road transport system is closely linked to the land-use system. The road system connects territories at all spatial scales (countries, regions, urban areas, municipalities, etc.). On the other hand, passengers and freight travel behaviour are strongly influenced both by land-use (the density and nature of activities and people for instance) and the road transport system (availability and costs of the different transport means).’

Peng Lu (2007) Saïd, there are different researchers who did more findings on how various characters of land use which mainly include: size, density and distribution affect the transportation. ‘Some studies suggest that land use mix plays a main role on urban transportation development’ (Simmonds, 1997

2.3.1. Traffic Analysis Zone (TAZ)

It is not easy for studying transportation demand of a specific area without doing category specification. Category specification in this context means: determining location extent of study, understanding socio economic characteristics of residences, and analyzing the trips behavior which takes place on the vast study area.

‘Delineating the study area boundaries into traffic analysis zone (TAZ) is forming special study areas for tabulating trip related data by specific characteristics of the study. Socioeconomic data include household and employment data for the study area that are usually organized into geographic units called transportation analysis zones (TAZs, sometimes called traffic analysis zones or simply zones). Traffic zones contain demographic and employment information, and are represented by special nodes called centroids. Each zone is attached, or "loaded," onto the network by specialized links called centroid connectors. Traffic outside the modeled area is represented by special centroids called external stations. These stations allow for the interaction of traffic flow between the region and the "outside world", while the interaction between all internal and external zones produces the actual traffic volume results for the entire region.’ (UTS, 2005)

TAZ boundaries are usually major roadways, jurisdictional borders, and geographic boundaries and are defined by homogeneous land uses to the extent possible. The TAZ structure in a subarea of particular interest may be denser than in other areas further away. In general, there is a direct relationship between the size and number of zones and the level of detail of the analysis being performed using the model; greater detail requires a larger number of zones, where each zone covers a relatively small land area.

The Addis Ababa City Administration has ten Sub-Cities which contains all the 99 Kebeles. According to the previous study of travel demand modeling for Addis Ababa, “Urban Transport Study and Preparation of Pilot Project for Addis Ababa” (2005), these Kebeles were used as traffic analysis zones. This is because, if a new TAZ other than Kebeles were developed, it will lead to no chance of using available socio-economic data for studying the travel demand of Addis Ababa and part of the sub-cities, Figure 2 below shows divisions of the zones used in the Ethiopian Road Authority (ERA) urban transportation study, 2005

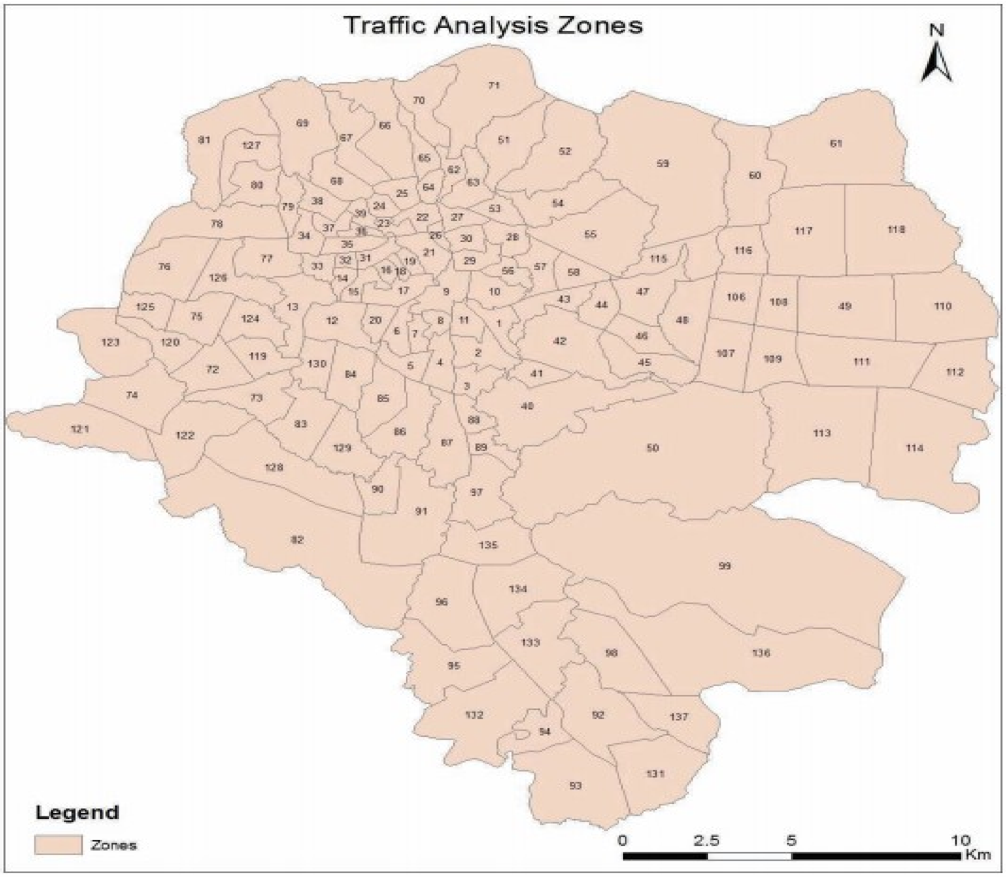


Figure 2 Zone divisions used by ERA urban transport study, 2005

2.3.2. Transport System Performance Evaluation Indicators

2.3.2.1. Mobility

Mobility is the ability and level of easiness of moving passengers, goods and services. For instance, rails which have specific and exclusive moving ways are more advantageous than other modes which use shared ways by minimizing the congestion and delays in travel times. Similarly, Bus Rapid Transit (BRT) systems with bus-only lanes that increases the efficiency of moving people while removing automobiles from the roads is an indicator for mobility performance of transportation. Enhancing the transportation systems mobility performance manages travel demand through innovative ideas to increase volume and capacity of transported passengers, goods, and services.

According to the Report from the Ministry of Transport of Ethiopia (2011), in the cities of developed nations' average mobility rate per person or trip/day is 2.5. However, the 2005 transport study by ERA shows that Addis Ababa mobility rate or average trip/day/person is 1.08.

In this respect the average length of mobility covered by vehicle was 3.3 km. and it was 1.5 km by foot. Also the report says ‘’In developed countries the length of mobility regarding walking is not more than 500 m.’’

2.3.2.2 Equity

The term equity means fairness; in transportation, it measures performances of the transportation system with regard to minimizing travel time, enquiring fair travel cost, availability of many other travel options, providing comfort for passengers, and open and available mobility for all level of passengers without any discrimination by any means.

2.3.2.3 Accessibility

According to Todd Litman (2017), Accessibility refers to people’s ability to reach goods, services and activities, which is the ultimate goal of most transportation activities. Many factors affect accessibility, including: mobility (physical movement), the quality and affordability of transportation options, transportatin system connectivity, mobility substitutes, and land use patterns. Accessibility in transportation system can be explained in terms of vehicle travel conditions, transportation network conditions, and adjoining factors in between transport demand and supply side. With regard to vehicle travel conditions; travel speeds, affordability, availability of other alternative modes, safety, convenience and comfort of each mode of the system to be analyzed.’

According to Karts and Bert (2004), ‘a number of components of accessibility can be identified from the different definitions and practical measures of accessibility that are theoretically important in measuring accessibility. Four types of components can be identified: land-use, transportation, temporal and individual.

(i) The land-use component reflects the land-use system, consisting of:
   (a) The amount, quality and spatial distribution opportunities supplied at each destination (jobs, shops, health, social and recreational facilities, etc.);
   (b) The demand for these opportunities at origin locations (e.g. where inhabitants live); and

(c) The confrontation of supply and demand for opportunities, which may result in competition for activities with restricted capacity such as jobs and school vacancies and hospital beds.

(ii) The transportation component describes the transportation system, expressed as the disutility for an individual to cover the distance between an origin and a destination using a specific transport mode; included are the amount of time (travel, waiting and parking), costs (fixed and variable) and effort (including reliability, level of comfort, accident risk, etc.). This disutility results from the confrontation between supply and demand. The supply of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transportation timetables, travel costs). The demand relates to both passenger and freight travel.

(iii)The temporal component reflects the temporal constraints, i.e. the availability of opportunities at different times of the day, and the time available for individuals to participate in certain activities (e.g. work, recreation).

(iv)The individual component reflects the needs (depending on age, income, educational level, household situation, etc.), abilities (depending on people's physical condition, availability of travel modes, etc.) and opportunities (depending on people's income, travel budget, educational level, etc.) of individuals. These characteristics influence a person's level of access to transportation modes (e.g. being able to drive and borrow/use a car) and spatially distributed opportunities (e.g. have the skills or education to qualify for jobs near their residential area), and may strongly influence the total aggregate accessibility result.'

2.3.2.4 Sustainability

According to Duranton and Guerra 2016, the transport system performance indicators are nested concepts; for instance, Traffic is a subset of Mobility, and Mobility is a subset of Accessibility. Transportation can be viewed from various perspectives: Vehicle Traffic is a subset of Mobility, which is a subset of Accessibility. Accessibility is the broadest perspective and so offers the most potential solutions to transportation problems, including more accessible land use development and mobility substitutes such as improved communications and delivery services.

Generally, sustainability is mainly seen as the promotion of environmentally friendly modes, and their accessibility for different social groups, while reducing dependence on transportation services owners.

Transportation system fulfilling all above the criteria of performance measurements is to be continual for present use and future requirements without any failure. This can be achieved if frequent study and update of the transportation system through effective analysis is to be performed.

2.4 Earlier Studies in Land use and Transportation Demand interaction of Addis Ababa.

In the course of this research, there were no previous studies that have been studied regarding the interaction of land use and transportation demand in Addis Ababa. However, Abel Desalgn, (2013) did his Master's thesis under the title of "Impacts of Freight Transport and Land Use Structure on Urban Traffic and Environment: the Case of Addis Ababa" and found that lack of Freight management practices and poor land use structure of the city has contributed to the problems associated to the city traffic functions and environment. The study was however specific to freight transportation only, thus public transportation problems and land use change connection were not grasped. But there are available studies on transportation demand of Addis Ababa.

The first very important study was, "Urban Transport Study and Preparation of Pilot Project For Addis Ababa, 2005", carried out by Consulting Engineers Services (India) P.L.C and SABA Engineering Private Limited. The client was the Ethiopian Roads Authority which was sponsored by The World Bank. The Study develops transportation framework / master plan, development of transportation data base, and capacity building of the Addis Ababa City Roads and Transport Authority. The Master Plan incorporated medium to long term travel demand of Addis Ababa.

The conventional four step transportation demand modeling were used and the sub model were Calibrated with the help of intensively collected household, road side, and traffic surveys data.

Even if it was a pioneer and well organized study, it couldn't analyze the problem of transportation system with regard to high rate of urban expansion and land use change. In addition, when evaluating the estimates of transportation demand for the year 2016, it couldn't match with the actual transportation demand which was recorded. It occurred because of the limitations on multi-dimensional view when forecasting the future transportation system problems. This mismatch may occur because of not analyzing the type and intensity of urban expansion and high rate of land use change observed which the main cause for many transportation demand problems was.

Recently, Babey Bezabih did his Masters research entitled "Analysis of Passenger Demand Forecasting Models within the Context of AALRT" during 2015 -2016. The objective of the research was to show that high growth rate of population and economic activity of Addis Ababa increases traffic flow resulting in high traffic congestion and imbalance between the demand and mode of transport. In the research,, the two major rail passenger transportation demand forecasting mechanisms were compared and the four step travel demand modeling was also used; but the research data for travel demand modeling were represented by six sample households in Kirkos sub city. This results for host generalization on travel demand model of Addis Ababa, since it can't represent the populations of Addis Ababa by six Kirkos sub city residents.

In addition, Asaye Melaku did his Masters research entitled "Travel Demand Modeling of the Addis Ababa East – West Light Rail Transport" during 2015-2016. The Author used a conventional statically-oriented and trip-based approach of the four step travel demand modeling technique. In addition, he adopted equations and models from the UTS (2005) Report. Even though he did best in forecasting the causes for future transportation demand but the research data were aggregated and analyzed by considering the kebele administratives as a traffic analysis zone. These results for the host generalization of each kebele have their own origin destinations relationships with the other kebeles. However, it is not the case for Addis Ababa kebele Administrations. With this regard, selecting specific study areas is the powerful and more interesting way in transportation demand study.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Ethiopia

Ethiopia, located in the horn of Africa, is a land locked country since the independence of Eritrea in 1993. It is bordered to the north by Eritrea, to the North-West by Sudan, to the South-West by West Sudan, to the South by Kenya, to the East by Somalia, and to the North-East by Djibouti. There are more than eighty ethnic groups. Ethiopia is the second populated nation in Africa with a total population of 82,101,998 of which 41,431,989 were males and 40,670,009 were females (Central statistics Agency of Ethiopia, 2011). Currently, there are nine regions and two special administrations in Ethiopia that are ethnically based. The area of Ethiopia is about 1.13 million square kilometers (sq. km). With regards to transportation, 'about seventy-five percent of the population does not have access to all-weather transport. Commuting (whether walking or using public transport) accounts for a large part of the time and cost to the poor' (The World Bank, 1996).

3.1.2. Addis Ababa

The capital and the largest city in Ethiopia, Addis Ababa, is a high land city located with geographical coordinates of 9°03´ North latitude and 38°42´ East longitude, approximately at center of the country.

Addis Ababa is sub-divided into 10 sub-cities where power is devolved to this smallest tier of administration. In rapidly growing urban areas, like Addis Ababa, access to land is being increasingly difficult by the conflicting demands of industry, housing, commerce, agriculture, land tenure structures and the need for open spaces. In the past few years, while Addis Ababa has witnessed an amazing horizontal expansion and rapid growth in urban population, it has not been provided with an equal growth in urban transportation provision which has resulted in increasing private car ownership, high congestion, increasing pollution and large number of road accidents

3.1.3. Akaki Kality

Akaki Kality is the second largest sub-city and the major industrial zone of Addis Ababa, located in the southern part of the city. It has an area of 118.08 sq. km. According to the Central Statistical Agency of Ethiopia 2017, the population of the Akaki Kality Sub-city was 106,645 males and 114,095 females which aggregated to 227,182 peoples living in the sub-city. The population density of the Sub-city then was 1,869 per sq.km. The sub-city is divided into 11 administrative woredas. The residents are a combination of factory workers, daily laborers, civil servants, military personnel and urban agriculturists. Figure 3 below illustrates description of the study area.

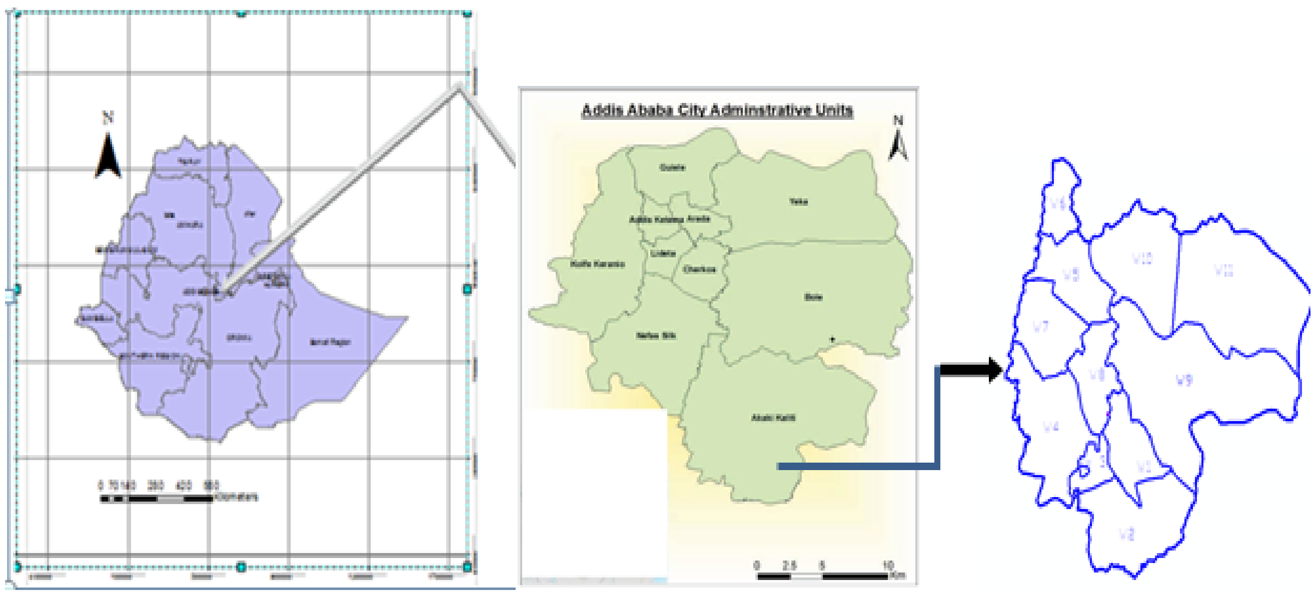


Figure 3: Description of the study area

3.2. Demographic characteristics of Addis Ababa

3.2.1. Population distribution of Addis Ababa

The trips for passengers mainly depend on two factors; their socio economic status and demographic status, so studying these two main factors will help the researchers to know how and why peoples travel. With this regard, population and employment characteristics along with income level of the study area will be analyzed in this study. Tables 1 and 2 below show the population and the proportion of males and females of Addis Ababa city in 2017 respectively.

Table 1: Population estimate of Addis Ababa

YEAR	2014			2015			2016			2017		
SUB CITY / GENDER	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
AKAKI KALITY	102,959	108,421	211,380	105,406	111,132	216,538	107,852	113,907	221,759	110,435	116,747	227,182
NEFAS SILK-LAFTO	172,907	195,976	368,883	177,016	200,876	377,892	181,125	205,892	387,017	185,461	211,025	396,486
KOLFE KERANIYO	240,983	259,180	500,163	246,709	265,660	512,369	252,436	272,293	524,729	258,480	279,081	537,561
GULELE	150,174	161,922	312,096	153,742	165,970	319,712	157,311	170,115	327,426	161,078	174,356	335,434
LIDETA	111,731	123,515	235,246	114,386	126,603	240,989	117,041	129,764	246,805	119,843	132,999	252,842
KIRKOS	120,120	137,915	258,035	122,974	141,363	264,337	125,828	144,893	270,721	128,841	148,505	277,346
ARADA	115,088	131,592	246,680	117,823	134,882	252,705	120,558	138,250	258,808	123,445	141,696	265,141
ADDIS KETEMA	144,954	152,839	297,793	148,398	156,660	305,058	151,842	160,572	312,414	155,478	164,575	320,053
YEKA	187,540	216,796	404,336	191,996	222,216	414,212	196,452	227,765	424,217	201,156	233,443	434,599
BOLE	168,545	191,842	360,387	172,550	196,639	369,189	176,555	201,549	378,104	180,782	206,573	387,355
ADDIS ABABA	1,515,001	1,679,998	3,194,999	1,551,000	1,722,001	3,273,001	1,587,000	1,765,000	3,352,000	1,624,999	1,809,000	3,433,999

Source : Central Statistical Agency of Ethiopia, 2017

Table 2: Proportion of male and female population of sub-cities of Addis Ababa, 2017.

Sub city / Gender	Male	Female	Total
AKAKI KALITY	49%	51%	100%
NEFAS SILK-LAFTO	47%	53%	100%
KOLFE KERANIYO	48%	52%	100%
GULELE	48%	52%	100%
LIDETA	47%	53%	100%
KIRKOS	47%	53%	100%
ARADA	47%	53%	100%
ADDIS KETEMA	49%	51%	100%
YEKA	46%	54%	100%
BOLE	47%	53%	100%
ADDIS ABABA	47%	53%	100%

Table 3 Distributions of populations among the sub cities of Addis Ababa, 2017.

SUB CITIES	population estimate, 2017	Proportion of populations	Area (sq. Km)	Proportion of Area	population density (peoples/sq. Km)
AKAKI KALITY-SUB CITY	227,182	7%	118.08	22%	1924
NEFAS SILK-LAFTO-SUB CITY	396,486	12%	68.3	13%	5,805
KOLFE KERANIYO-SUB CITY	537,561	16%	61.25	12%	8,777
GULELE-SUB CITY	335,434	10%	30.18	6%	11,114
LIDETA-SUB CITY	252,842	7%	9.18	2%	27,543
KIRKOS-SUB CITY	277,346	8%	14.62	3%	18,970
ARADA-SUB CITY	265,141	8%	9.91	2%	26,755
ADDIS KETEMA-SUB CITY	320,053	9%	7.41	1%	43,192
YEKA-SUB CITY	434,599	13%	85.98	16%	5,055
BOLE-SUB CITY	387,355	11%	122.08	23%	3,173
ADDIS ABABA	3,433,999	100%	526.99	100%	6,516

Source: Central Statistics Agency of Ethiopia, 2007

3.2.2. Income and Economic Status

According to the estimate of Central Statistical Agency of Ethiopia, in 2017 for Addis Ababa, 62.8% of the total populations were economically active and 37.2% of the populations were economically not active. From the economically active populations, 79% were employed and 21% s was unemployed. From the employed population, 16.8% s were Government employees, 17.8% s were Government Development Organization Employees, 50.7% s were private organization employees, 2.7 % s were NGO Employees, and 12% were domestic and other employees.

According to the 2007 report of the CSA, there were about 65,200 households with average household size of 4.1 and an average monthly income of Birr 725 and of these 50% of the population had monthly income of Birr 467.7 which is below poverty line.

3.3. Method of Data collection

Primary, secondary, and tertiary data were used for accomplishing the research.

Primary data included, but not limited to:

- Traffic counts (cordon surveys) to understand the trip production and attraction of the selected destinations from Akaki Kality sub city at peak hour;
- Travel time measurement for the links between selected destinations from Akaki Kality sub city;
- Field observation to understand the type and synchronization of vehicle fleets on the transportation system; and
- Visual observations on the road networks to understand the surface condition and service performance.

Secondary data included:

- Existing and future Road Plan Map of the sub cites in Auto CAD and ArcGIS file format, were acquired from the Addis Ababa City Roads Authority;
- Registered vehicles by mode type and year of registration by sub cities were acquired from the Addis Ababa Transport Authority;
- Driver license data of the last three years by type of license and by sex structure of drivers were acquired from the Addis Ababa Transport Authority;
- Land Use Map was acquired from the Addis Ababa Land Management Office;
- Satellite image of the Sub City for past years was download from internet ;
- Data related to trip characteristics such as: trip patterns, reasons for trip, and trip frequencies;
- Number of employed workers and students in Akaki Kality sub city;
- ➢ Historical demographic data such as the Socio-economic characteristics of the dwellers in the Sub-City (revenue, size of households, average age, and occupation) were acquired from the Central Statistics Agency of Ethiopia.

Tertiary data included: ERA Urban Transport Study, 2005 Report and related findings from different researchers. Table 4 below shows the acquired data type and source.

Table 4: Research data type and Data source

No	Data	Format	Source	Period
1	Demographic Characteristics of Addis Ababa	Excel	CSA	2007
2	Addis Ababa Road Plan map	Auto CAD	AACRA	2016
3	Registered vehicles by category in Addis Ababa sub cities	Excel	Driver and vehicle control Authority	2015_2017
4	Addis Ababa Public transportation use weekly report	Excel	Addis Ababa Transport Authority	April-June (2017)
5	Addis Ababa and Akaki Kality Land Use Map	ArcGIS & Auto CAD	Akaki Kality Land Management bureau	2016
6	Urban Transport Study-Final Report	Pdf	ERA	2005
7	Satellite imagery data for Addis Ababa	image	Land sat imagery source	1988-2017
8	Number of students in Akaki Kality sub city	Excel	Akaki Kality Education bureau	2015-2017
9	Number of Employed workers in Akaki Kality sub city	Excel	Akaki Kality human resource and development bureau	2015-2017

3.4. Software used

In analyzing the data, the following software were utilized:

- **Microsoft Excel spread sheet**; it is a tool which is used for statistical, mathematical, and graphical analysis of the data. In this regard; demographic data, passenger's trip data, vehicle related data, and land use attribute data's were analyzed using this tool.
- **Arc GIS 10.2**; Geographical information system software, which has the capability of capturing, storing, analyzing, querying, and retrieving of spatial and non-spatial data. In this regard, road infrastructure plan maps, land use land cover maps which can be expressed by positional values are spatial data; whereas, non-spatial data are descriptions, attributes and other information's for the spatial data which will be stored in the form of data base. The image classification process is upervised, in which the process of image classification is altered by the users specified class or unsupervised in which case the process of image classification is not altered by the user. In this research, supervised classification was dealt with.

3.5. Method of data Analysis

When looking into the Akaki Kality sub-city, the land use type is mixed of residential, industrial, commercial, agricultural, wet land, and forests without zonal demarcations. This results in complexity of establishing a well-planned, manageable, sustainable, cost- effective and accessible transport system in the sub city. Even if the type of land use is mixed without integrated zonal activities and difficult to gather, analyze, manipulate, and reach conclusion about the transport characteristics of the sub city, it is however possible to conduct a reliable transport demand analysis to plan, design, and implement the current and future transportation system. With this regard, the transportation demand analysis in conjunction with studying the land use type by assigning zones for the study area need to be performed and the main focus of this research was directed to that.

As mentioned above, primary, secondary, and tertiary data were used in this research. For analyzing such data; statistical, mathematical and graphical analysis were dealt with too.

3.5.1. Methods on Transportation Demand analysis

In this research, for studying the transportation demand of the Akaki Kality sub city, the four step transport demand modeling was dealt with. Data related to demographic characteristics: like number of population by sex and age structure, household size, household income, car ownership, employment opportunity, travel time, and travel cost for home-based and non-home based trips were collected and encoded into excel spread sheet. Then, by considering daily trip as dependent variable and all the above inputs as independent variables trip production and trip attraction equations for different trip purposes to were adopted from the 2005 urban transport studies and comparative analysis were done.

By performing cordon surveys, it was possible to estimate the base-year trips originated from Akaki Kality and destined to Akaki Kality and was possible to calibrate constant parameters. For trip distribution analysis, five destination nodes from Akaki Kality the Addis within Ababa sub cities were selected regarding Saris, Bole, Legehar, Megenagna, Autobes Tera, and Ayer Tena Taxi stations. By using the Gravity model, origin-destinations trip matrix formulated. For doing so, weather travel distance and travel time was used as deterrence functions.

For modal split Analysis, the Logit Model was utilized in which it was based on utility or customer's satisfaction. The customer's choice for different modes was evaluated based on travel comfort, travel cost, and mode accessibility. Traffic Assignment Analysis was performed in relation to availability of alternative routes for the selected traffic analysis zones which was the major tackling problem in the case of the Addis Ababa Roads. For doing this, Short path distance analysis was performed.

3.5.2. Methods of land use analysis

There were two tasks to conduct land use analysis; the first task was performed in the case of the urban expansion study. This was done by dealing with satellite imagery which was captured in the past years. The images were classified by supervised classification technique, when the patterns were classified according to the proximity of the color, then the patterns were digitized to establish the boundary area of the class and the change to be detected with spatiotemporal analysis. When doing so, the type of urban expansion takes place in Addis Ababa, and hence the Akaki Kality Sub city was determined. The expansions are not mostly centroid, which takes place in radial distance around specific center, but leap frogging which is the type of urban expansion takes place by forming different sub urban center. Furthermore, the expansions is also Less in fill, which is resettlements on the existing built up area aimed to increase population density to provide different infrastructural services together; but more of green fill, in which the type of urban expansion is based on new settlements on areas where there is no infrastructural service built before.

The second task is detail land use study, which is mainly on built up areas to know the contribution of residential, commercial, industrial, and other components land use on highly growth of built up areas by collecting land use related data which is stored in GIS or Auto CAD file format from Akakai Kality sub city and Addis Ababa Land Management Office. By using these data, the information were grouped under attribute and location identities and exported to Excel spread sheet for further analysis.

3.5.3. Methods of transportation demand and land use interactions

As transportation development is one part of infrastructural services development, it is shaped by the type and intensity of urban expansion. In addition, it is clear that transportation services shape the type of settlements. The distribution of populations among the sub cities were summarized from the population estimate of 2017 and the proportion of areas in respect of each sub city were analyzed. Then future settlements and land use changes were forecasted using regression analysis, and future transportation demand and service needs were estimated.

'Transportation and land use interactions mostly consider the retroactive relationships between activities, which are land use related, accessibility and transportation related. These relationships have often been described as a classic "chicken-and-egg" problem since it is difficult to identify the triggering cause of change; do transportation changes precede land use changes or vice-versa? There is a scale effect at play as large infrastructure projects tend to precede and trigger land use changes while small scale transportation projects tend to complement the existing land use pattern. Further, the expansion of urban land uses takes place over various circumstances such as infilling (near the city center) or sprawl (far from the city center) and where in each case transportation plays different roles' (Abel, 2013)

3.6. Procedures

The conduct of this research will follow procedures as depicted in Figure 4 below..

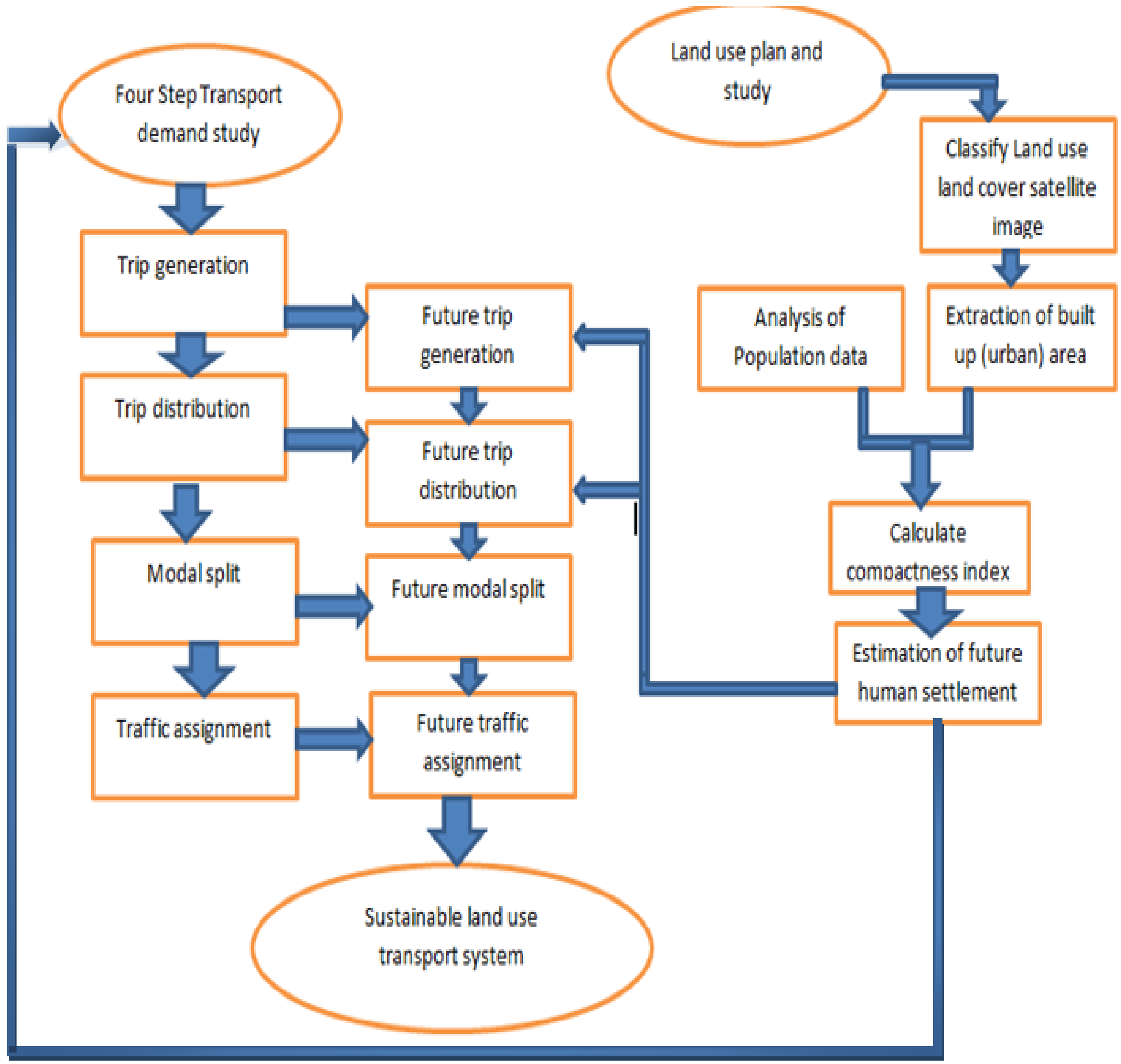


Figure 4: Producers followed in this research

CHAPTER FOUR

4. DATA ANALYSIS AND RESEARCH FINDINGS

4.1 Analysis on urban expansion of Addis Ababa

This rapid growth of population has put tremendous pressure on the urban spaces in the city. The large proportion of this growth appears to be in slums and squatter settlements in the city. In response to this acute demand, efforts are being made by the city government to incorporate the peripheral areas of the city, which is resulting in hastening the sprawl of the built-up area of the city and a rapid physical expansion.

To study the overall urban expansion of Addis Ababa which took place in the past few years, satellite imagery was acquired for the years 1988, 2000, 2011, and 2017 and used in this study. In this regard, the images were classified into five major land use and land cover classes by using the Arc GIS software. The classes were: Built-up, Urban Agriculture, Forest, Water Body, and Barren Land. Using the classified imagery, Spatial-Temporal Analysis and detecting the change of land use pattern were performed. The intention is to understand the extent of urban expansion (built up) which was observed and has direct influence on transportation service development,

For identifying the change in land use, color theory has been used which is one of the way to show spatial distribution of land use and land cover. The following figures show the situation of land use change within the last 29 years.

Addis Ababa is a commercial and political center and exemplary of the rapid urban growth of Ethiopia. The rapid urban and metropolitan growth in Addis Ababa is exacerbated by poor planning and land-use, inadequate infrastructure, and chronic housing shortage. A key challenge for housing in the Addis Ababa metropolitan area, and, indeed, of planning in general, is that lack of coordination with transportation.(AACTA,2016)

According to Meles (2005), Addis Ababa has always been a sprawling city, from when it originated in 1886 as a military settlement, part of Emperor Menelik II's campaign in taking over its territory. Throughout its history it has been continuing to sprawl due to its spontaneous and unplanned nature. Until 1988, the majority of the area for Addis Ababa is covered with urban barren lands and forests. The major urban built up area is concentrated at somewhere around center (piazza). The type of urban expansion observed is concentrated mono centric. Figure 5 below illustrates the land use map of Addis Ababa in 1988.

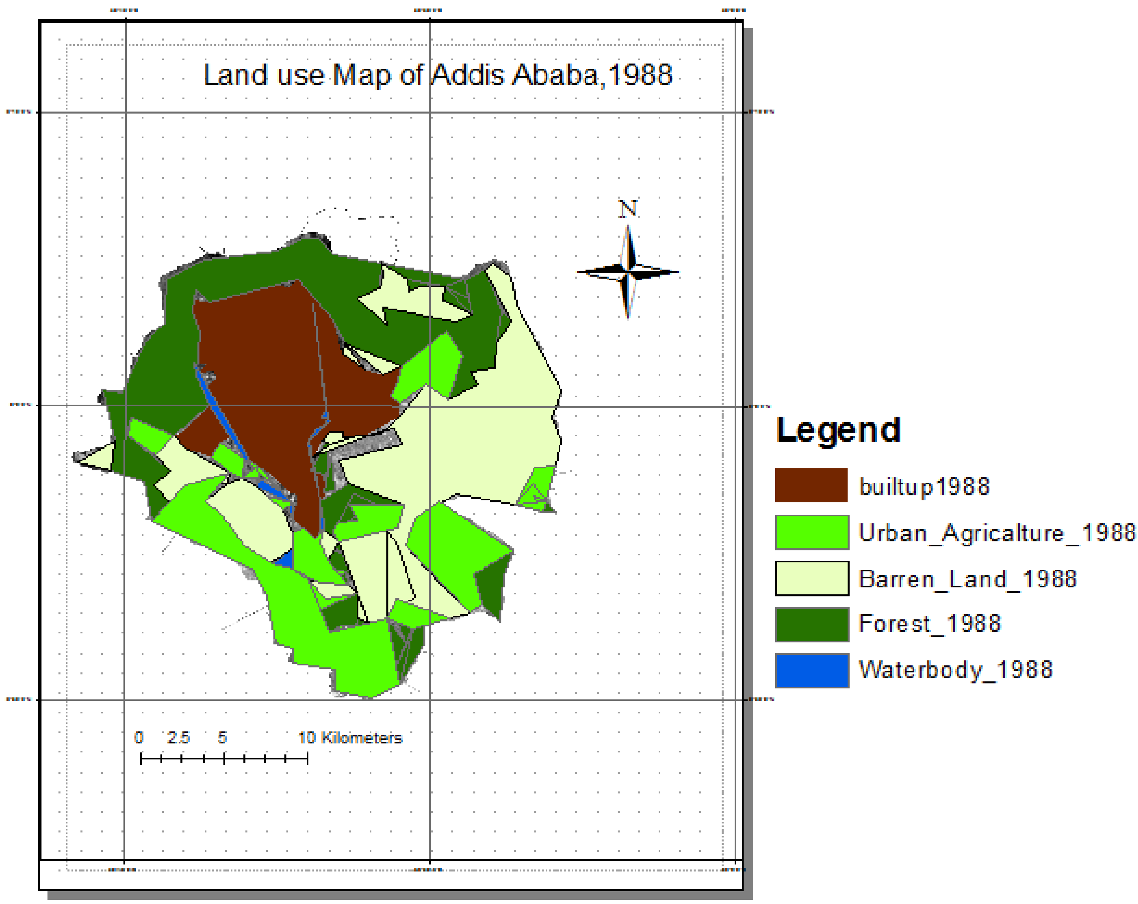


Figure 5: Land use map of Addis Ababa, 1988

As the result of the city expansion during 1994 – 2007, many farmers on the peripheries lost their livelihoods and were forced instead to turn to other forms of casual labor within the city.

During this period, the city has experienced special spread mostly toward the southern, eastern and south-western directions. The spread is depending on topographical circumstances and availability of road networks, which is proved as the expansion takes place in the direction of exit road corridors from Addis Ababa. Figure 6 below illustrates the land use map of Addis Ababa in 2000.

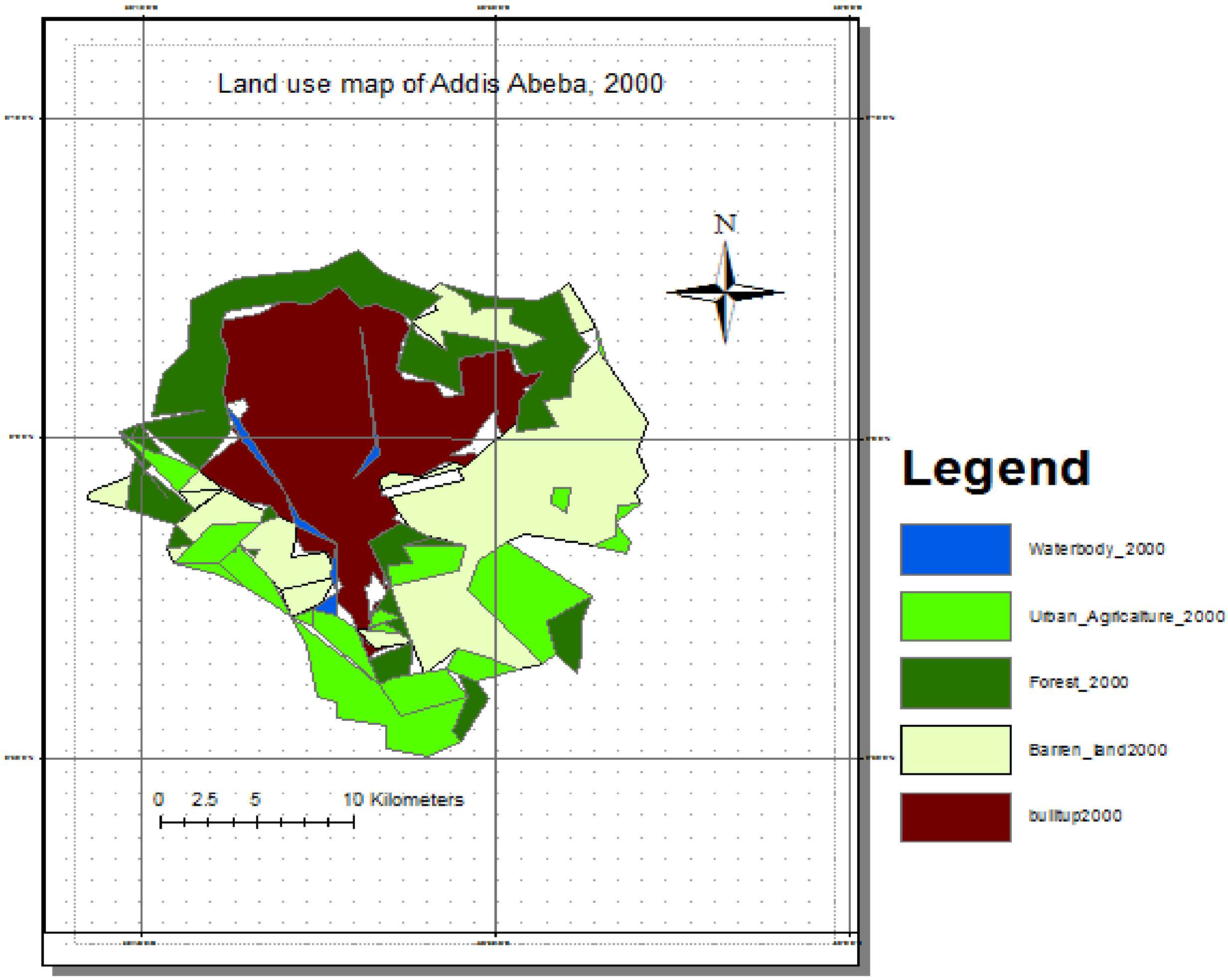


Figure 6: Land use map of Addis Ababa, 2000

This stimulated the development of the Oromia Special zone that was created in 2008 in order to ease the co-operation and development of the surrounding areas of Addis Ababa and to control the urban sprawl of this city encroaching the lands of the Oromia people.. Figure 7 below presents the land use map of Addis Ababa in 2011.

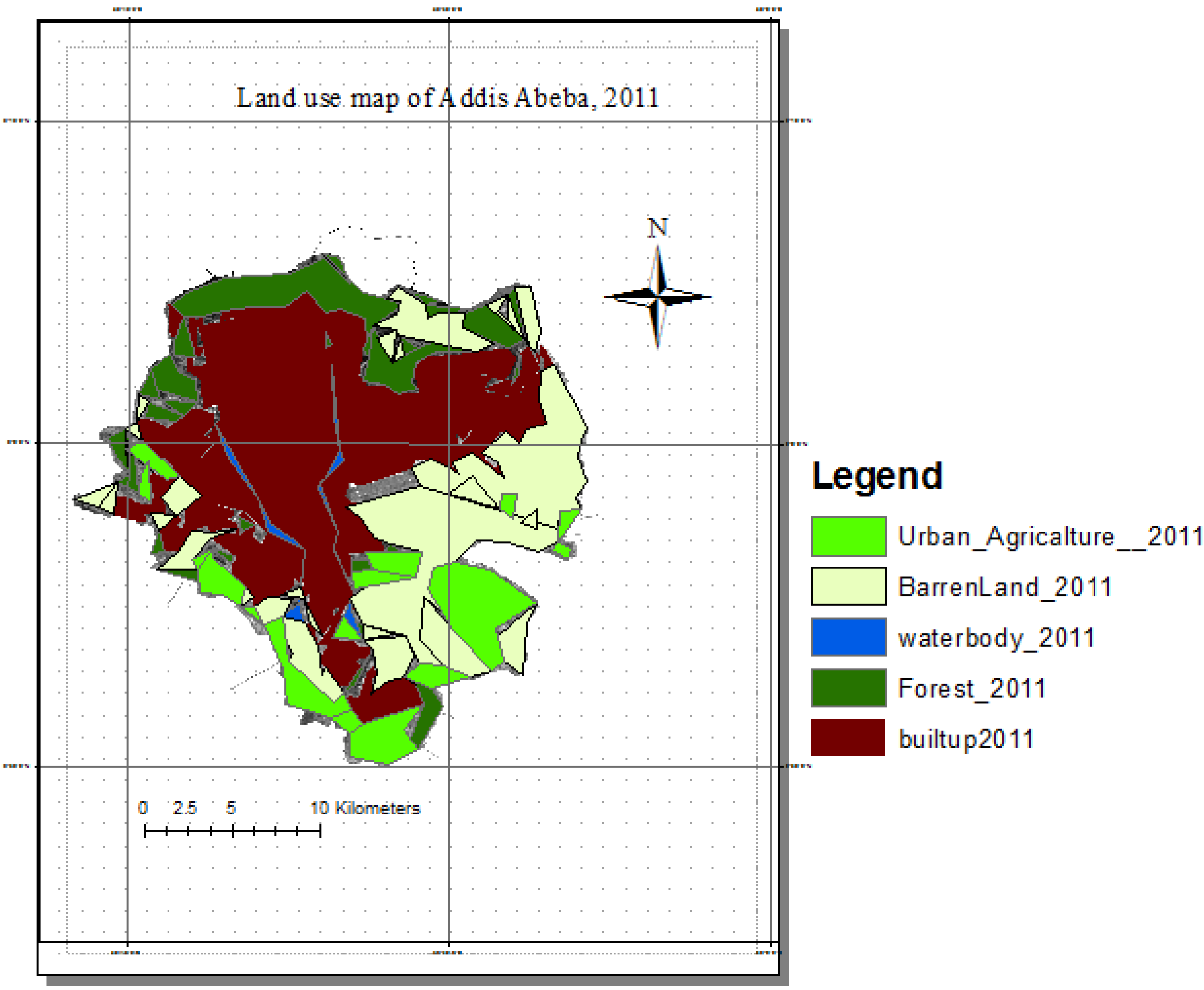


Figure 7: Land use map of Addis Ababa, 2011

When observing Addis Ababa in 2017, it has been experiencing continual growth and change mostly in all directions, but the rate of expansion for different part is varying in extent, and rate. Forests, barren lands, and urban agricultures are transforming into built-up areas (residential, industrials, commercials, and service centers) in high growth rate. This expansion of built-up area requires the availability of efficient transportation services to handle the transportation demand for instance in the transportation of goods, services, and passengers. Figure 8 below presents the land use map of Addis Ababa in 2017.

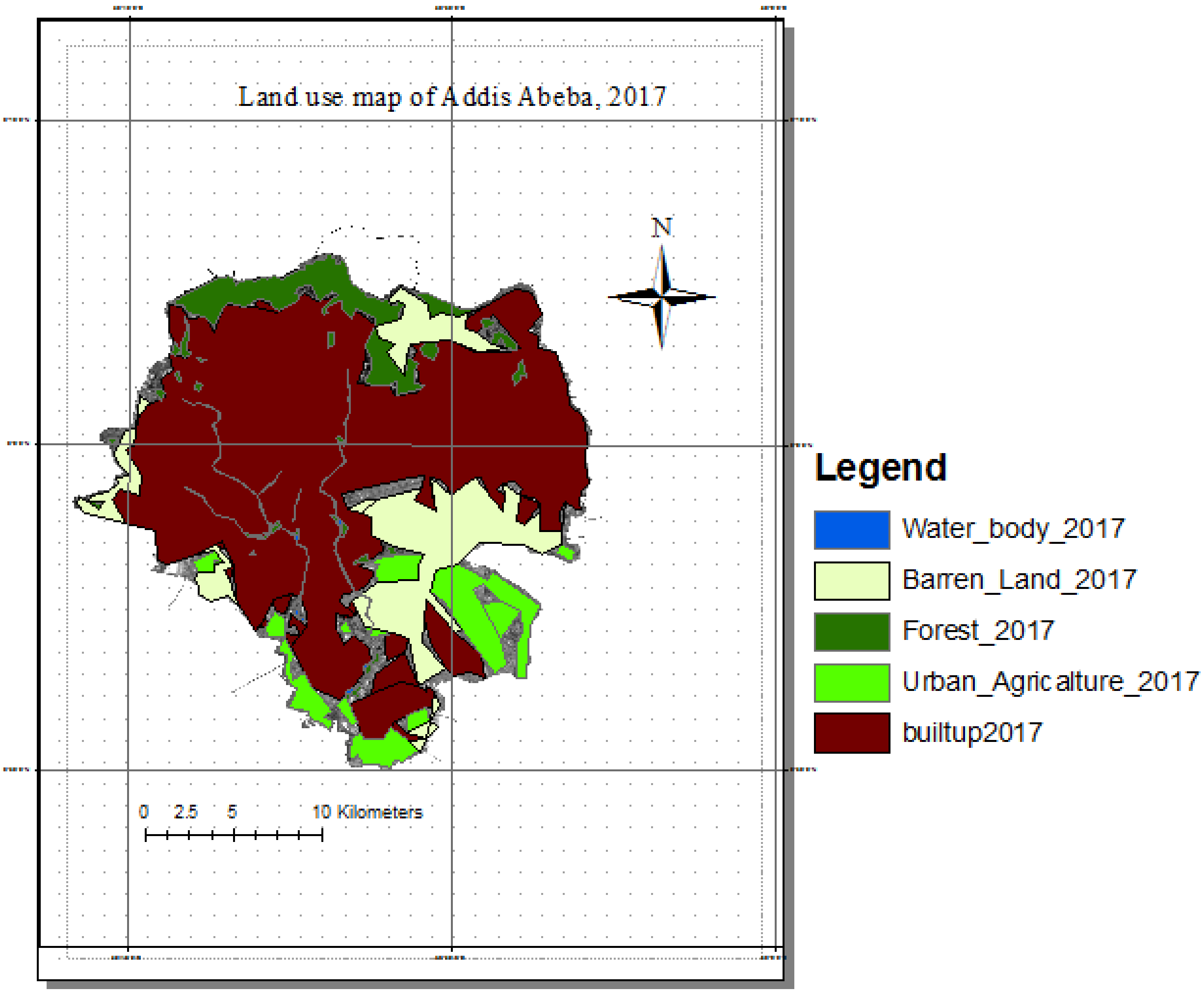


Figure 8: Land use map of Addis Ababa, 2017.

The construction sector is also clearly booming with office blocks, residential housing and hotels that are coming up everywhere, cranes dot the horizon and old buildings are being ripped down every day. When summarizing the above figures, the observed changes in land use and land cover of Addis Ababa in the past few years are quantified in Area (km2). Table 5 below shows the land use and land cover change of Addis Ababa City during 1988-2017. and subsequently Figure 9 illustrates the land use and land cover change of Addis Ababa during 19888-2017 G.C

Table 5: Land use and land cover change of the Addis Ababa, 1988-2017 G.C

	Land use / Land cover Type						
Year (G.C)	Water body (km2)	Forest (km^2)	Urban Agriculture (km2)	Barren land (km2)	Built up (km2)	Unclassified (km2)	Total (Km2)
1988	5	146	109	165	109	6	540
2000	5	101	87	151	161	35	540
2011	5	50	59	137	242	47	540
2017	5	34	41	71	333	59	540

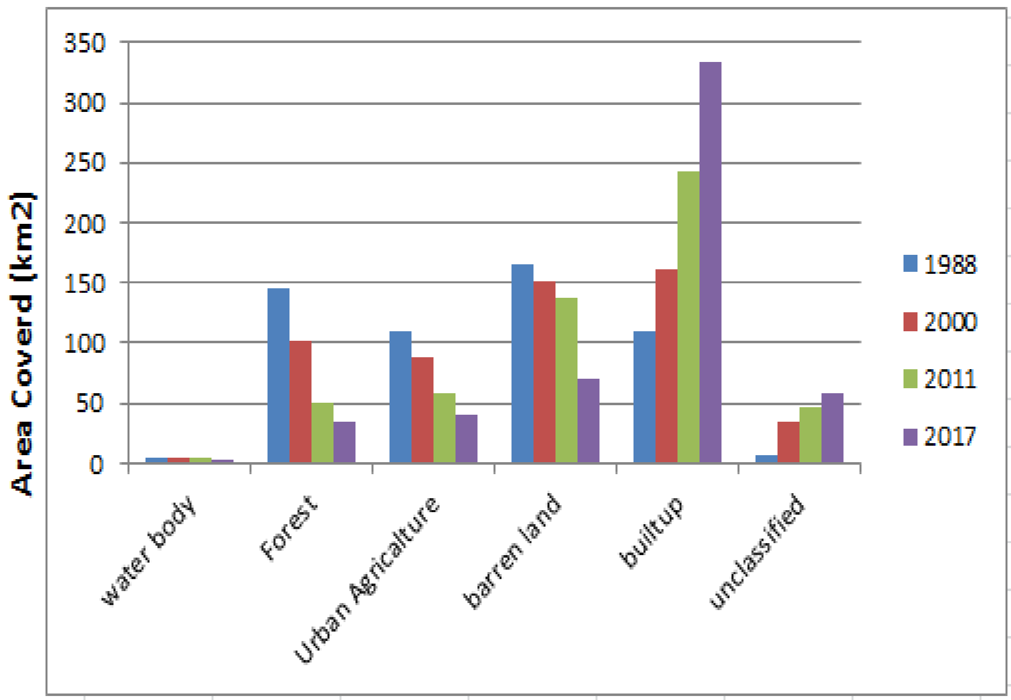


Figure 9 Land use Land cover change of Addis Ababa, 19888-2017 G.C

From 1886 to 1936፣ the development trend of the city was characterized by fragmented settlements. According to Melese (2005), 'following the Italian occupation in 1937, the process of physical development of Addis Ababa in the period from 1937 to 1975 was focused more on expanding the built-up area of the city by compact development and consolidation of the former fragmented settlements'. From the period 1988 to 2000 however, the city's built-up area showed a tremendous increase of 32.3% from the total area of 109 km^2 in 1988 that shoots up the cumulative total to 161 km^2 in 2000. Similarly from the period 2000 to 2011, the city's built-up area showed an increase of 33.3% from the total area of 161 km^2 in 2000 that shoots up the cumulative total to 242 km^2 in 2011. Furthermore, from the period 2011 to 2017, the city's built-up area increased by 27.3% from the total area of 242 km^2 in 2011 that shoots up the cumulative total to 333 km^2 in 2017.

On the other hand in 1988, the area covered by forest in Addis Ababa was 146 km^2 but it decreased by 44.6% and reached 101 km^2 in 2000. However, the area dramatically decreased by 102% and reached 50 km^2 in 2011. The degradation went down by 47% and reached 34 km^2 in 2017.

Similarly in 1988, the area covered by Urban Agriculture was 109 km^2 but decreased by 25.3% and reached 87 km^2 in 2000. Again this area decreased by 47.5% and reached 59 km^2 in 2011. The decrease went further down by 43.9% and reached only 41 km^2 in 2017.

In 1988 the area covered by Barren-Land was 165 km2 but it decreased by 9.3% and reached 151 km2 in 2000. Again the Area decreased by 10.2% and reached 137 km2 in 2011. The decrease continued by 93% and reached only 71 km2 in 2017. The percentage changes of each land use and land cover of Addis Ababa for the last 29 years are presented in Table 6 below.

Table 6: Percentage changes of each land use and land cover of Addis Ababa, 1988-2017 G.C.

	Land use covered (Km^2) by Land use / Land cover Type					
Year (G.C)	Water Body	Forest	Urban Agriculture	Barren land	Built-up	Unclassified
%increase 1988_2000	0.0	-44.6	-25.3	-9.3	32.3	82.9
%increase 2000_2011	0.0	-102.0	-47.5	-10.2	33.5	25.5
%increase 2011_2017	0.0	-47.1	-43.9	-93.0	27.3	20.3

This expansion of the city was characterized by the development of scattered and fragmented settlements in the peripheral areas of the city, with both legal residents and informal settlements. With this regard, horizontal expansion took place in all peripheral areas of the city, where both legal and illegal settlements were established.

There are about 94,135 housing units built in the city between 1984 and 1994. Out of this, 15.7% (14,794 housing units) were built by squatters. According to Melese (2005), in 2000, Addis Ababa had estimated total housing units of 60,000, including informal settlements. This figure was 20% of the total housing stocks of the city and the total area occupied by squatter settlements was estimated at 13.6% of the total built-up area.

Generally, while Addis Ababa is expanding horizontally to accommodate the increasing population as a result of natural growth and in-migration from all corners of the country, the public transportation system failed to meet the increasing demand generated from sprawled settlement at the peripheries. Spatial sprawl and increasing transportation demand are concurrent trends that need coordination among actors and policies for sustainable development.

Furthermore, according to the Urban Transport Study Report (2004/2006), the transportation system of Addis Ababa is characterized by low availability of road with only 7% of whereas 20% to 25% is required for the efficient system. In addition, the prevailing poor transportation management in the city exacerbates the situation.

Due to different reasons, the city administration could not provide adequate urban transportation system to cope up with the rapid increase in population with annual growth rate of 3.8% Addis Ababa Transport Authority (AATA,2016). For example estimation in extent of the expected future urban expansion and residential development is not easily and reasonably forecasted. To find solution to this problem, detailed land use study in conjunction with analyzing the urban expansion was performed. The detail of land use share analysis from the built up area of recent data is the other way of analyzing the dependency of transportation services development on urban settlement. In this regard, the built-up area was again studied in detail according to the share of land use patterns using the 2016's Addis Ababa Land Management Data Records. Figure 10 below presents the land use patterns of Addis Ababa in 2016.

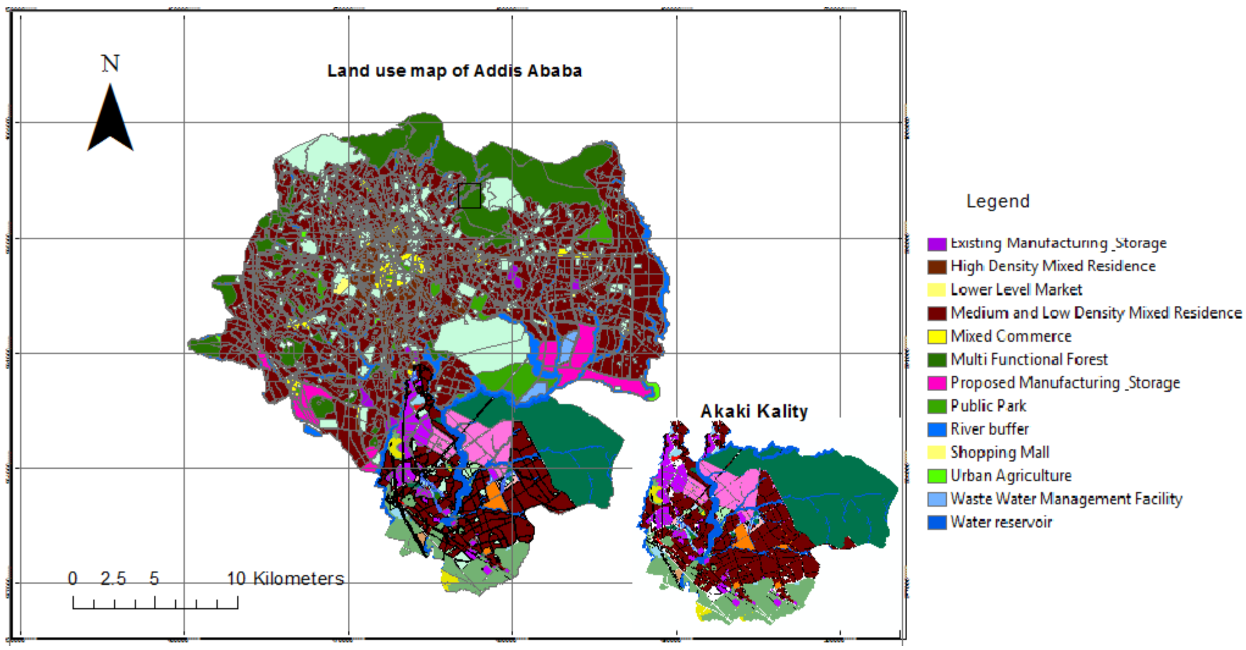


Figure 10: Land use patterns of Addis Ababa, 2016

In terms of overall urban development, although the Ethiopian government is making attempts regarding planning and catering for the rapid urban growth, urbanization still takes place largely in planned/unplanned way. In recent years, the rate of spatial expansion of the city is outpacing the rate of population growth, resulting in a less than efficient overall physical form. Figure 11 below presents the percentage of land use/cover of Addis Ababa in 2016.

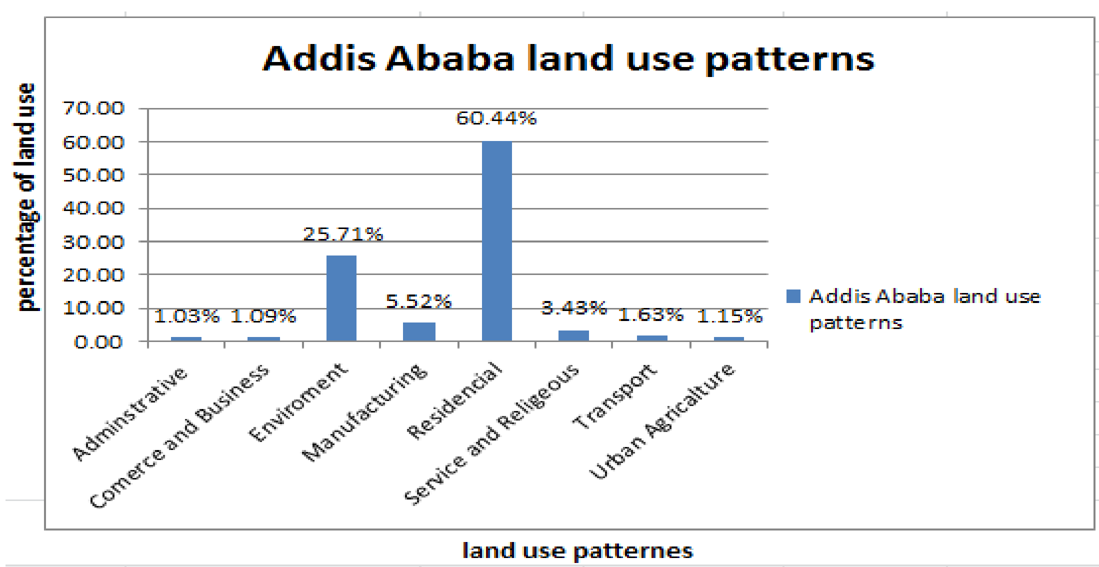


Figure 11 Percentage Land use/cover of Addis Ababa, 2016.

As presented in Figure 11 above, the residential areas contributed 60.4% of the total which represents high density to low and medium density. The second largest coverage is environmental with 25.71% of the total that includes regional and public parks, rivers, and multi-functional forests. Manufacturing encompasses industries, retails, factories, and ware houses which covers 5.52% of the total area. Most of these entities are located around Sebeta, Akai Kality, Saris, Burayu, and Sululta. Similarly, transportation (roadways, railways, parking, and terminals), accounts for 1.63% of the total area. Services and religious places including, cultural and civic centers, cemeteries, festival sites, fire & emergency services, municipal gardens, churches, mosques, health centers, schools, ply grounds, power and telecom sub-stations, solid waste management facilities, and waste water Management facilities in aggregate account for 3.43% of the area.

Urban agriculture is not surprising for having 1.15% of land use coverage of Addis Ababa, because there is moderate area which is still under use for farming purposes mostly around Akaki Kality area which is directly contributing to the livelihood of the residents of Addis Ababa. Commercial and business centers cover 1.03% of the total area of Addis Ababa, which is the least contributor of area coverage following the administrative building areas. Figure 12 below presents percentages of land use/cover of the Akaki Kality sub-city in 2016.

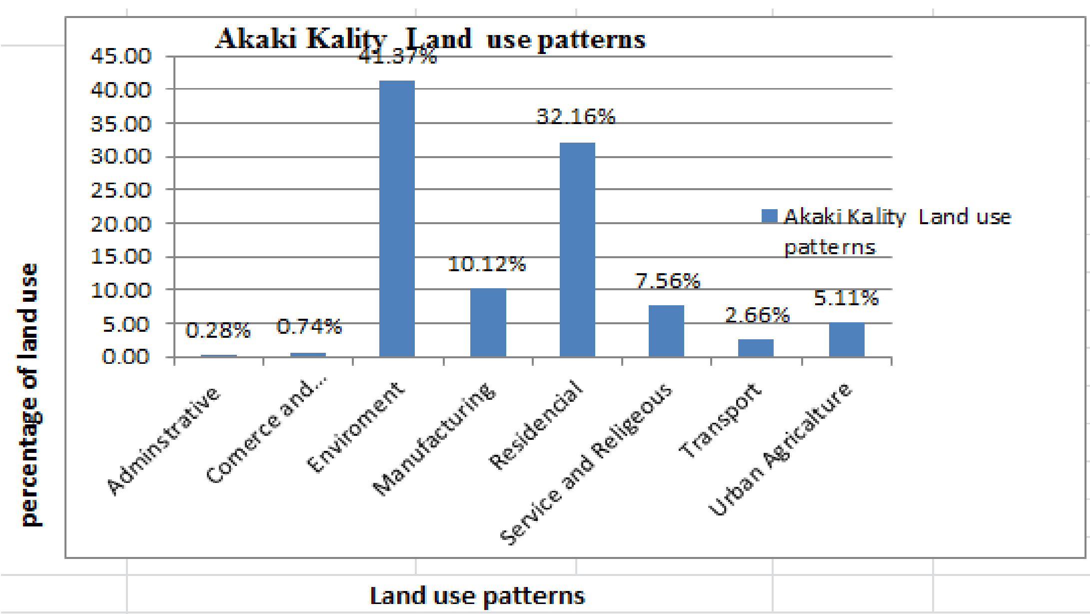


Figure 12: Percentages of Land use/cover of Akaki Kality, 2016.

According to Figure 12 above, residential areas contribute 32.16% of the total area where high density to low and medium density residential areas are located. The largest percentage coverage of the area is environmental, which accounts for 41.37% of the total which includes: bare lands, regional and public parks, rivers, and multi-functional forests. Furthermore, manufacturing accounts for 10.12% of the total area of the Akaki kality sub-city incorporating: industries, retails, factories, and warehouses.

The percentage contribution of transportation (roadways, parking, and terminals for taxi, bus, and heavy trucks) is 2.66% of the total area. In addition, services and religious places including, cultural and civic centers, cemeteries, festival sites, fire & emergency services, municipal gardens, churches, mosques, health centers, schools, play grounds, power and telecom sub-stations, solid waste management facilities, and waste water management facilities aggregately amounts to 7.56% of the total area.

Since there are vast areas which are still in use for urban agriculture around Akaki and Kality sub city, crop cultivation through traditional farm and grass cultivations for feed are currently practiced having the percentage of land use has the value of 5.11%. Commercial and business centers account for 0.74% of the total area of the sub-city, which has the least contribution of land use coverage followed by the administrative buildings, having 0.28% of the total area of Akaki kality Sub city.

4.2 Transportation Demand Analysis of Addis Ababa

4.2.1 Registered vehicles in Addis Ababa

Public transportation problems are not new in the capital city which is becoming increasingly serious for many reasons. According to Mintesenot (2007) Addis Ababa's transportation problem is exacerbated due to an aging fleet of vehicles, chaotic movements of minivan taxis, limited number of city buses and unbalanced road infrastructure. Such problems have contributed to uneven fare across the transportation system, which can be very expensive both for users and providers. On the other hand, factors that diminish the growth of congestion is low motorization rates in Addis Ababa which are very low by global standards. In order to improve public transportation in Addis Ababa, substantial investments in mass transportation network have been made or identified. The current public transportation provision/operation has a number of weaknesses, with governance being a critical one. Even though most trips in Addis Ababa are made by walking, facilities for pedestrians tend to be inadequate and substandard. Integrating transportation with land-use development has also proven to be very difficult in Addis Ababa. (AATA, 2016)

As availability and accessibility of vehicle fleet is part of transportation supply, analysis of the registered vehicles on their type and distribution in the sub cities of Addis Ababa is a serious concern. In this regard, the numbers of vehicles by category for the year 2016 were analyzed. Figure 13 below presents the number of registered vehicles by category in the city of Addis Ababa in 2016.

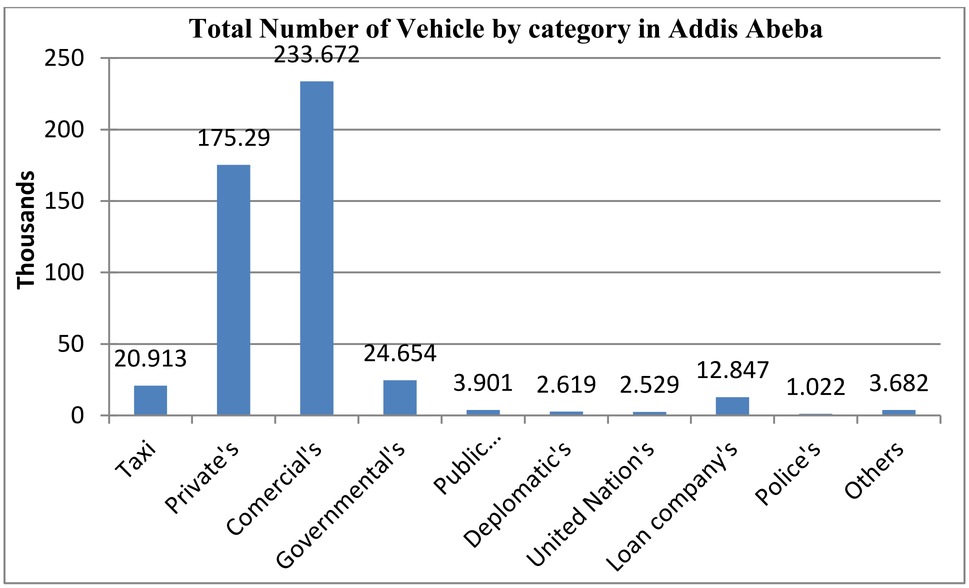


Figure 13: Number of registered vehicles by category in Addis Ababa, 2016

Source: Addis Ababa Transport Authority, 2016

To combat these problems, the Government is actively implementing several schemes, including expanding road coverage to accelerate traffic flows, improving mass transportation systems by expanding city bus services, and introducing a separate mass transportation services to civil servants.

For instance, the Addis Ababa Anbessa City Bus Service Enterprise, which started providing services with five buses in 1943, has invested huge amounts of money to increase its bus fleet has introduced new routes to different parts of the city. The Enterprise currently bears the brunt of the city's mass transit services, with 714 buses transporting 700,000 commuters every day. The blue and white taxis are the second major public transport providers in Addis Ababa. Currently, the estimated number of such taxis is about 7,000, while the number of taxis bearing regional states' plates and providing auxiliary services is 11,000. These numbers, however, are constantly fluctuating, and an exact figure of how many commuters use these taxis is not reliably available.

According to the Addis Ababa City Road and Transport Bureau (AACRTB,2016), the number of taxis in the city is decreasing from year to year. The private sector's interest to join the taxi business has significantly declined. Taxis are becoming old, and insignificant number of new vehicles registers to take taxi plates. Taxi owners say that after paying for fuel, regular repairs, and given the current road infrastructure, the taxi sector is not profitable.

In 2011, the city's Transport Bureau established a taxi zoning system for the blue and white city taxis in an effort to create a system beneficial for taxi users, owners and operators, by saving money and time. One of the major objectives of the taxi zoning system was to prevent taxis from refusing to travel long distances to maximize their income, but users and operators claim that the system has made things worse. In addition to efforts by the Government, some private sector entities have also made attempts to address lack of public transportation. A few years ago, a private transport company, Alliance City Bus joined the sector to provide a more organized form of transportation, but it is difficult to say that it has achieved its goal. Due to high volumes of traffic and lack of road infrastructure along its planned routes, the company is not performing as expected,

Recently, the 34.25 km rail network is currently underutilization with 10 light trains and is considered a symbol of the country's economic growth. Each train can carry 317 passengers. In its first phase, the AALRT will possibly provide transportation services to 10 main stations and 20 smaller stations across eight of Addis Ababa's 10 sub-cities. Kolfe Kenario, Gulele, and the major parts of the Akaki Kality sub-cities are not included on the current service. The AALRT has the capacity to transport 60,000 passengers per hour, when it becomes fully operational. Long queues at the stations could be seen. The AALRT lines from Kality to Menilik Square (Piazza) traverses the major transportation demand generating centers of: Meskel Square, Mexico Square, Lideta and Merkato that are open and busy transporting passengers from 6 A.M. in the morning to 10 P.M. in the evening.

Currently, the trains travel at a maximum speed of 30 km per hour but their maximum speed is 80 km per hour. Despite the excitement at the beginning of the AALRT, change on the transportation system will not solve the city's transportation crisis. It is difficult to say the AALRT would solve the traffic problem fully, but it could bring relief to some passengers. Taxi and bus transportation should be worked on along with expanding the AALRT fleet,

The Addis Ababa City Administration has a Traffic Management Agency, Public and Freight Transport Authority and Drivers and Vehicles Inspection and Control Authority as autonomous entities under AACRTB. The recent transportation policy recommends that public transportation in the city should shift to mass transportation systems, currently envisioned to include the railway, buses and to some extent midi buses. In line with the policy, Bus Rapid Transit (BRT) is expected to be the next big transportation system, to be made effective over the coming years. AACRTB is currently encouraging taxi owners to use their associations, of which there are 13, to adapt by transforming their businesses into mass transportation share companies. The AALRT will create significant improvements to the city's transportation system, but several additional and diverse operations need to undertake along with this new operation.

4.2.2 Analysis of drive license in Akaki Kality sub-city (2015-2017)

Accounting the registered vehicles in Akaki Kality sub city, analysis on the current drivers and estimating of future expected driving license which may be owned from the yearly increments is summarized. Table 7 below shows the number of driving licenses registered in Akaki Kality sub-city in the past three years. Next, Figure 14 shows the number of driving licenses in 2015, 2016, and 2017 and subsequently, Table 8 presents the incremental percentages of driving license in the Sub-city

Table 7: Driving licenses registered in Akaki Kality sub city for the past three years.

License type / Year	Motor	Auto	Taxi2	Hezb1	Hezb2	Dereq1	Dereq2	Dereq3	Fesash1	Fesash2
2015	57	625	397	420	109	122	303	235	87	21
2016	90	754	483	529	75	175	376	264	180	6
2017	41	792	762	618	111	163	669	290	228	12

Source: Addis Ababa Driver & Vehicle Control Authority

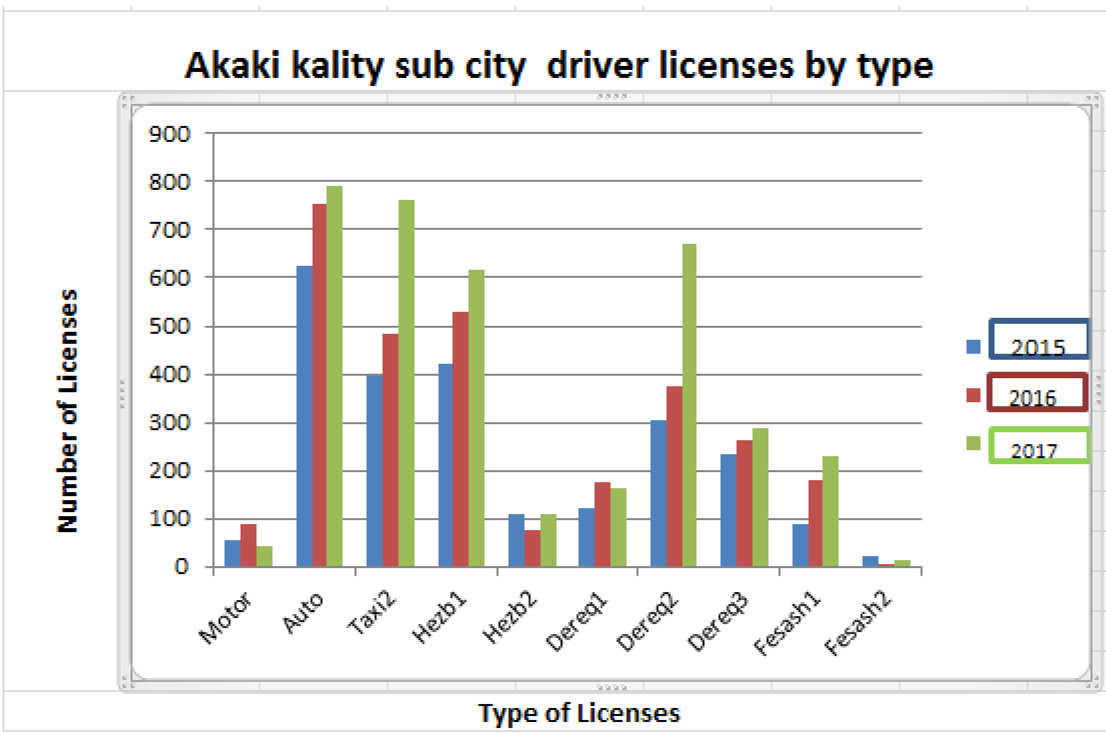


Figure 14: Number of driving license in Akaki Kality 2015, 2016, and 2017.

Table 8: Percentage increment of driving license in Akaki Kality Sub City

license type	Motor	Auto	Taxi2	Hezb1	Hezb2	Dereq1	Dereq2	Dereq3	Fesash1	Fesash2
Increment/Decline from 2015/2016	58%	21%	22%	26%	-31%	43%	24%	12%	107%	-71%
Increment/Decline from 2016/2017	-54%	5%	58%	17%	48%	-7%	78%	10%	27%	100%

From the above figures, if passenger transport system is to be considered, people prefer to acquire auto and taxi driving licenses to bus driving license. This indicates that in the future people will incline to have automobiles instead of using public transportation system and this will exacerbate the limitations in fixed land use assets. These problems are manifested by the absence of adequate road infrastructural service, resulting in traffic jam, vehicle emissions and accidents in the transportation systems. Figure 15 below graphically illustrates the number of driving licenses owned by people dwelling in Akaki Kality by sex Ratio.

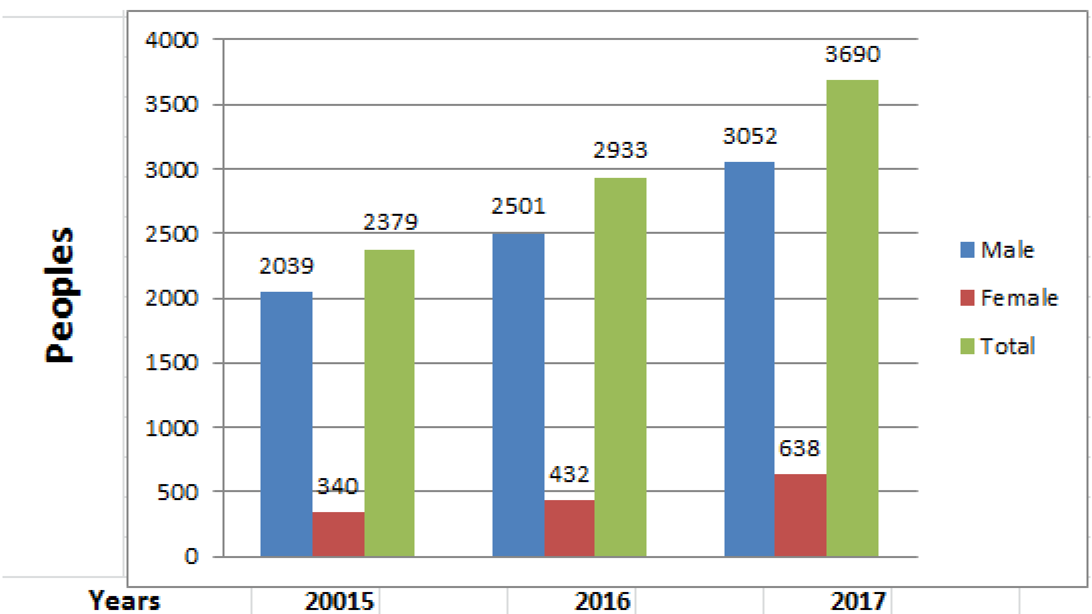


Figure 15: Number of driving license owned in Akaki Kality by sex Ratio.

From Figure 15 above, one can observe that the participation of females in vehicle driving area has grown from year to year. For instance, the number of female drivers in 2015 was 16% of the total drivers, in 2016 they accounted for 17% of the total, and also in 2017 the number increased to 20%. The increment of female drivers from year to year has significant role in minimizing the probability of occurrence of traffic accidents as compared to male drivers. In the contrary, the preference of having private automobiles which has less passenger car equivalence is more by females, so automobiles in the traffic system will be increased and traffic congestion and jam on the street will be more.

4.2.3 Passenger trip characteristics

Urban public transportation in Addis Ababa is performed by both public and private operators. The modes of urban transportation system in the city are generally categorized as motorized and non-motorized transport. These include: public bus, minibus (shared taxis), individual taxis, private cars, and non-motorized transport, while walking and animal carts dominate the periphery.

Though the term public transport refers to all types of transport systems; road, rail, and water transport, as in most of the Sub-Saharan African cities, the modalities of public transport mobility in Addis Ababa is limited to the road transport that basically comprises of shared taxis (minibuses) and buses. Currently, taxis, city buses and private cars altogether cover 30 percent of the urban mobility modes while 70% of urban mobility is covered on foot (AACATA, 2016).

The demand for efficient and affordable public transport is increasing with the sprawl of urban areas and increasing economic activities. The residential areas being developed at the edges of the city scream for a very acute demand of public transport to accommodate travel to the city center where all activities; markets, offices, entertainment areas, etc, are concentrated. These and other unforeseen problems seemingly made private car ownership the best means of transport available. Moreover, this rapid increase of private cars, mostly very old, has resulted in a very high air and noise pollution in the city (AACATA, 2016). However, a large proportion of the city's population is still crucially dependent on public transport services.

Table 9 below presents the average daily trips by public transport modes in Addis Ababa sub cities in 2017 and subsequently Figure 16 illustrates the average daily trips by public transport modes in Akaki Kality sub city in 2017.

Table 9: Average Daily Trips by public transport modes in Addis Ababa sub cities 2017.

V.Type / S. City	Code-1 Minibus	Code-3 Minibus	Higer Bus	Isuzu kitket	Fedral Transport	Sheger Bus	Aliance Bus	Public Bus	Anbesa Buss	Total travel
Lideta	73,728	168,768	17,280	23,520	0	2,520	0	36,000	3,600	325,416
Kolfe	30,600	59,760	8,400	8,160	0	4,830	0	2,240	7,200	121,190
Adis Ketema	47,712	114,240	5,200	8,400	0	3,360	3,150	765	200	183,027
Gulele	39,396	42,816	1,120	0	0	9,800	0	4,760	18,400	116,292
Arada	25,488	66,240	10,750	3,600	0	840	2,000	10,080	25,000	143,998
Kirkos	60,288	36,000	5,920	1,600	0	10,850	0	2,940	1,280	118,878
Bole	72,576	76,896	0	2,800	0	2,160	80	360	2,160	157,032
Yeka	49,248	41,760	10,400	3,000	5040	6,120	360	8,160	16,800	140,888
Akaki Kality	21,024	48,000	11,016	9,312	0	4,320	3,600	840	5,100	103,212
Nifas Silk	50,232	38,052	0	3,060	0	6,440	100	840	11,500	110,224
Total travel	470,292	692,532	70,086	63,452	5040	51,240	9,290	66,985	91,240	1,520,157
%	30.9	45.6	4.6	4.2	0.3	3.4	0.6	4.4	6.0	100.0

Source: Addis Ababa Transport Authority, June 2017

The above figure doesn't provide the share of the private car because the data available in the authority is only about public transportation!

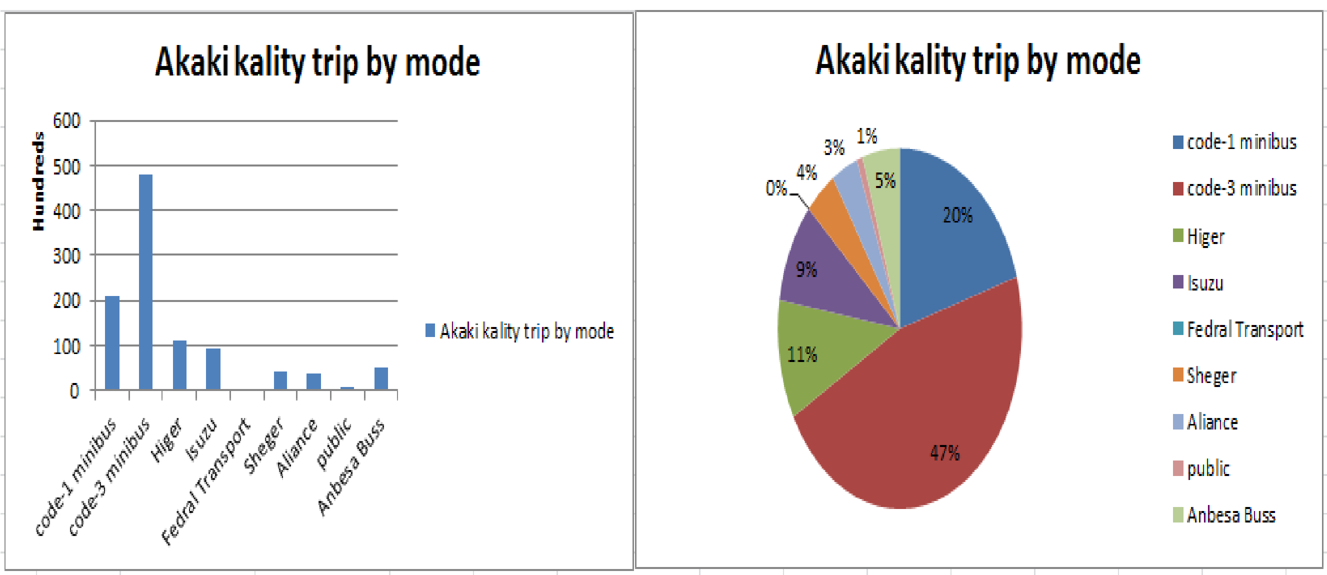


Figure 16: Average daily trips by public transport modes in Akaki Kality sub city, 2017

4.2.4. Transportation infrastructure in Addis Ababa

According to the report from AACRA official website,2011, 'The development of the roads in Addis Ababa started as of the foundation of the city by Emperior Minilik II in 1894 when the Emperor undertook the construction of the roads from Addis Ababa to Addis Alem and from the palace (presently located in the area known as Arat Kilo) to the British Embassy.Even if it wasn't highly successful, the Emperor Menilik had brought in rollers (stone crushers) and tried to construct modern roads with the help of local laborers. During that time, only the roads from the palace to 'Entoto Genet' and Addis Alem were successfully upgraded into modern standards while the rest were doomed to be muddy in the winter and dusty in the summer times. Again, Emperor Menilik, imported two vehicles to Addis Ababa in 1899 by the end of his reign. However, up to 1912 E.C, movement in and around the city was limited to using mules and horsebacks with most of the roads being nothing more than mule trails. Better and modern road construction did not materialize in Addis Ababa until the era of Emperor Hailesellasie I. It was during his reign that road construction began to be undertaken in a modern and extensive manner. During this time, a new office, 'The Public Works Department' was set up, with the objective of constructing new roads and upgrading the existing ones in and around the city of Addis Ababa. This new Public Works Department that was formed at the start of Hailesellasie's reign was upgraded into a ministerial level and the city developed its own organization henceforth.During the reign of Hailesellasie I, the road section from Legahar to Akaki_Kality was connected which is known as the Debrezeit Road, being the most heavily used, until the ring roads was developed to provide relief for inner city traffic and for cross-city traffic.'

Since the past years, the Addis Ababa Road network has developed in radial form shaped by the five regional exits. Recently, the road system in Addis Ababa is devided into the follwing four classes:

i. **Arterial street:** This class of roads has continious traffic flow in the network. This includes; intra-urban and inter-urban public transport networks. The road is composed of radial and ring roads having 30 to 120 m reserve width.

ii. **Sub Arterial Streets:** This type of roads serve for lower level intra-urban and inter-urban mobility than arterial streets and can connect adjoining areas having 25 to 30 m reserve width.

iii. **Collecter Streets:** These are minor public streets used to collect and distribute the through traffic to and from local streets and provide accsess to arterial and sub arterial streets. Most of the time, these type of streests are arranged in grid system.

iv. Local streets: This type of streets provide accsess to residentials, bussinesses, or other neighboring properties; similarly, these type of streets are arranged in grid system.

The Urban Transport Study (2004/2006) noted that, a primary arterial, sub-arterial, collector and local streets are designed to accomodate a maximum capacity of 3,700, 2,100, 1,440 and 680 vehicles per direction per hour respectively. Figure 17 below illustrates the road map of Addis Ababa and subsequently Table 10 presents the road length of Addis Ababa and Akaki Kality sub city in 2016.

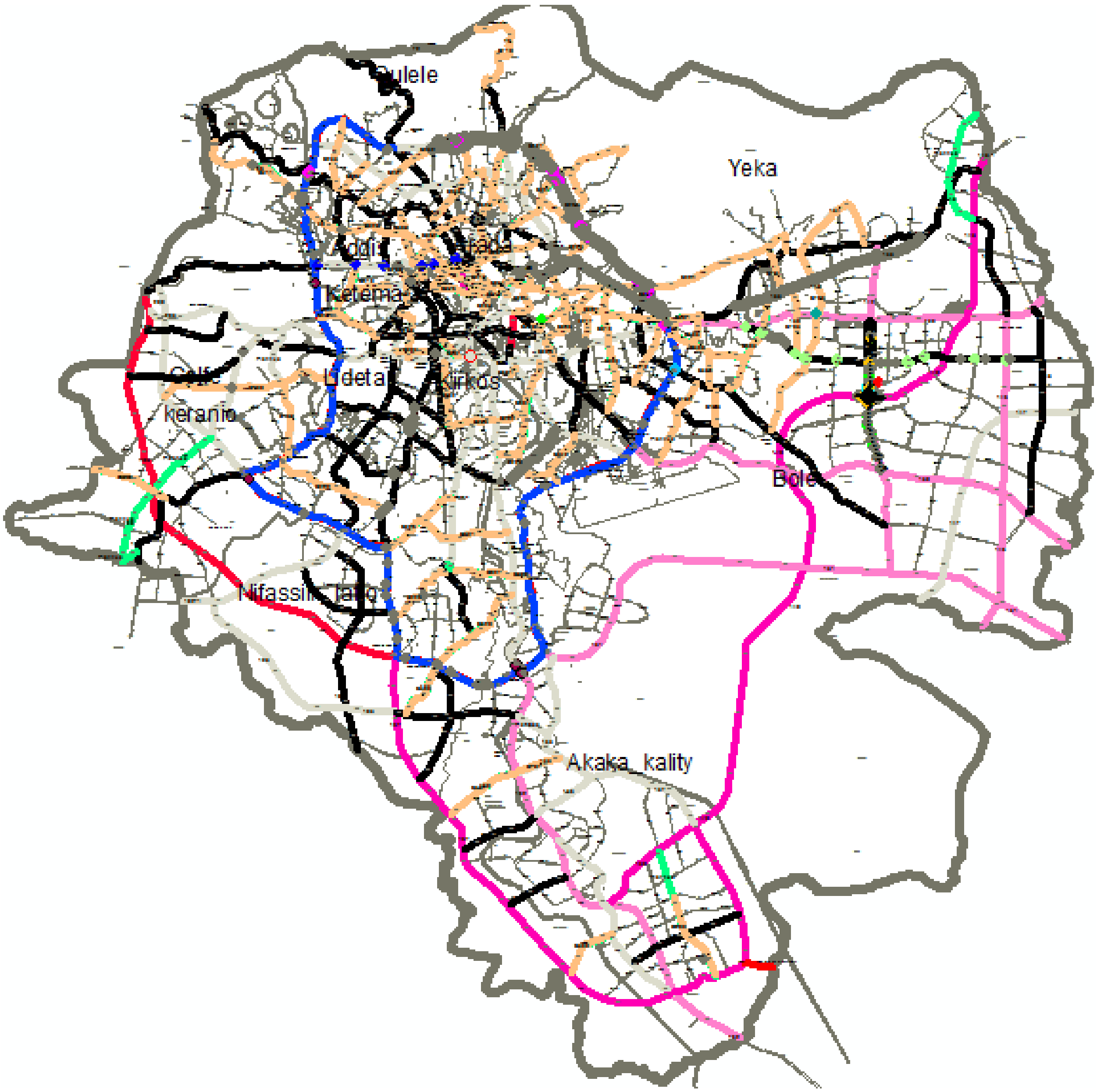


Figure 17: Road map of Addis Ababa, 2016

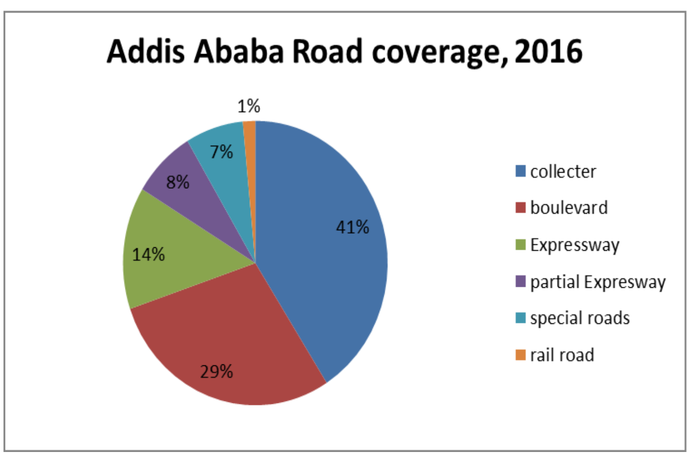
Source: Addis Ababa City Road Authority

Table 10: Road Length of Addis Ababa and Akaki Kality sub city, 2016

Road / For	Collector (km)	Boulevard (km)	Expressway (km)	Partial Expressways (km)	Special roads (km)	Rail road (km)	Total Road coverage (km)
Addis Ababa	592	417	201	112	102	22	1446
Akaki kality	47	19	18	3	3	3	93

Source: Addis Ababa City Road Authority

Addis Ababa has been making a concerted effort to improve the urban transport situation, largely through large investments in new infrastructure, including roads, a new Light Rail Transit (LRT) system and plans for a new Bus Rapid Transit (BRT) system, and improved standards and practices for improving and integrating pedestrian facilities in major transport capital projects. It has invested heavily in its road asset stock, with 26 percent of its capital investment budget dedicated to transport. These investments in the road network may provide less economic and mobility value for residents than their planners may have intended. Indeed, at the current low rates of motorization, the frequent and ubiquitous congestion in the city suggests substantial shortcomings in how traffic is managed, rather than a fundamental mismatch between transport supply and demand. (AACRA, 2016). Figure 18 below illustrates the Addis Ababa and Akaki Kality road coverage by type in 2016.



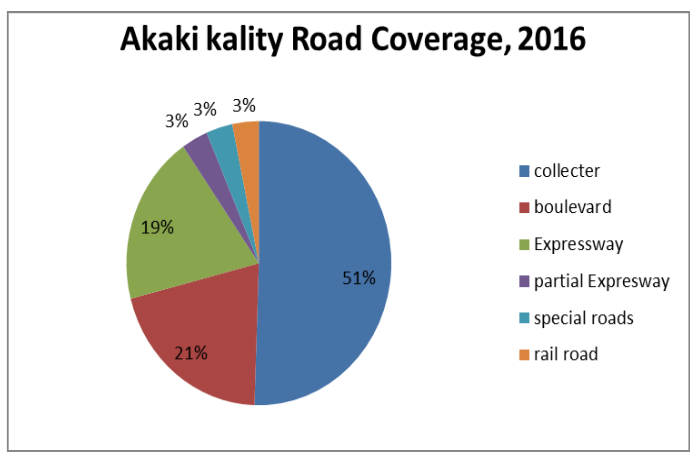


Figure 18: Addis Ababa and Akaki Kality road coverage by type, 2016

Mobility index and road density is the mechanism of measuring effectiveness of the roads in the specified area. Road density can be measured as the ratio of the total road network in the area to the total area or to the total population in that area. Higher road density value implies that as there are available transport routes resulted for higher directedness and connectivity level within the networks. On the other hand, lower value of road density implies that there is insufficient road infrastructure for serving the demand. Road density evaluates the network structure considering only from the supply side where as road density with regard to population context measures the availability of network distance per person. Table 11 below shows the road density of Addis Ababa and Akaki Kality Sub-city.

Table 11: Road density of Addis Ababa and Akaki Kality sub city

For	Total Road (km)	Area (Km2)	Population (10,000's)	Road Density (km/km2)	Road Density (km/1000persons)
Addis Ababa	1,446.00	540.00	335.00	2.68	0.43
Akaki Kality	93.00	118.08	22.17	0.79	0.42

Road density with regard to population shows there are some areas with less road coverage. Especially when looking the peripheral areas of Addis Ababa including Akaki Kality.sub city.the road density looks small. But the road density for Addis Ababa seems good, but the conditions for most of the Roads are not quite good. Due to this transportation problems are increased with regard to supply side.

4.3. Transportation demand analysis of the Akaki Kality sub-city in respect of six selected zones

Transportation planning is the most data intensive and time consuming works requiring strong coordination of different planning sectors with much more resource allocations. Due to these reasons, it is not advisable to perform transportation planning activity by a single agent or person. With this regard, for studying the transportation demand of Addis Ababa, models, equations, parameters, and information have been adopted from the Consulting Engineering Services (India) Pvt. Ltd that carried out a study in 2005 in collaboration with Saba Engineering Pvt. Ltd. The client was the Ethiopian Roads Authority (ERA). According to the study the four stage travel demand modeling, mostly known as sequential travel demand modeling was applied. The distribution of land use in terms of population and employment allocation is done exogenously in this type of modeling process. The modal is validated and viable for the horizon year 2020.

The four steps involved in the studies were:

i. Trip Generation;
ii. Trip Distribution;
iii. Modal Split; and
iv. Traffic Assignment.

4.3.1 Trip Generation

It is the first step of modeling activity, which has two parts, namely trip production and trip attraction**.** Multiple linear regression equation is used in this step as follows:

$$Y = b_0 + (b_1x_1) + (b_2x_2) + (b_3x_3) + \ldots + (b_nx_n) + e$$

Where**:**

Y= dependent variable;

Xi = independent variable (i= 1, 2, 3…n);

b0 = constant term;

bi = coefficient of independent variables (i= 1, 2, 3…n);

e = error term; and

n = number of observations.

The above multiple linear regression equation was utilized to generate trip production and trip attraction for Addis Ababa. The dependent variables in this case is the trips produced from or Attracted to particular zone and the independent variables are all the socio economic activities which causes trip for passengers. Assumptions for Multi Linear Regression are: for any specific value of the independent variable x, the value of the dependent variable must be normally distributed about the regression line. The standard deviation of each of the dependent variables must be the same for each value of the independent variable.

4.3.2 Trip production

The term trip production is used for trips generated in each traffic zone associated with residential areas. The trips were classified according to trip purposes; home-based work trip, home-based education trip, home-based other trip, or none home-based trips. For trip production, there were almost 20 results of regression equations developed in the Urban Transport Study of 2005. However in this research, five of these equations were adopted. The following relationships were used in the process.

i. Total trip production = 1.0584 'X' Population number, where R^2 is 0.93;
ii. Home-based work trip production = 1.48 'X' Number of workers, where R^2 is 0.94;
iii. Home-based education trip production = 1.684 'X' Number of students, where R^2 is 0.9;
iv. Home-based other trip production = 0.199 'X' population number, where R^2 is 0.73; and
v. None home-based trip production = 0.023 'X' Population number, where R^2 is 0.45.

4.3.3 Trip Attraction

Unlike trip production, trip attraction is associated with trips attracted to the non-residential end like: work places, schools, shopping areas etc.. Ttrip attractions are also specified by trip purposes, work trips, education trips, other trips and none home-based trips. The main independent variables which affect trip attractions are, employment, student enrolment, distances from the central business district (CBD), etc..

There were eight results of regression equations for trip attraction models developed in the urban transport study of 2005. In this research however, five of these equations were adopted from the previous study and are depicted below. Why are the numbers of equations reduced?

i. Total trip attraction = 3.919 'X' Employment, where R^2 is 0.89
ii. Total work trip attraction = 1.57 'X' Employment, where R^2 is 0.88
iii. Total education trip attraction = 1.61 'X' number of Student Enrolment, where R^2 is 0.5
iv. Total other purpose trip attraction = 0.86 'X' Employment, where R^2 is 0.7

v. Total none home-based trip attractions = 0.0695 ’X’ Employment where R^2 is 0.6.

In this research, trip generation characteristics of Addis Ababa and Akaki Kality sub city were analyzed as follows by using the above adopted equations.

For trip production, the population data were forecasted for four consecutive years (2014, 2015, 2016, and 2017) and the urban transport study trip production equation which was explained above. In addition, for trip attraction analysis, the 2007 Central Statistical Agency employment data were used. In dealing with this, government employees were considered. It has been recorded that about 70% of the total employees in Addis Ababa have their own works. Having this employment data and using the Urban Transport Study Trip Attraction Equation, trip attraction analyses were conducted in this study and results for the four consecutive years are presented in Table 12 below.

Table 12: Daily trip production and attraction for Addis Ababa sub cities.

Year	2014		2015		2016		2017	
Sub cities	Production	Attraction	Production	Attraction	Production	Attraction	Production	Attraction
Akaki Kality	223,724	232,306	229,183	237,975	234,709	243,713	240,449	249673
Nefas Silk-Lafto	390,425	405,402	399,960	415,303	409,618	425,331	419,640	435,738
Kolfe Keraniyo	529,372	549,679	542,291	563,093	555,373	576,677	568,954	590,779
Gulele	330,322	342,993	338,383	351,363	346,547	359,841	355,023	368,641
Lideta	248,984	258,535	255,062	264,846	261,218	271,238	267,607	277,873
Kirkos	273,104	283,580	279,774	290,506	286,531	297,522	293,543	304,803
Arada	261,086	271,101	267,462	277,722	273,922	284,429	280,625	291,389
Addis Ketema	315,184	327,274	322,873	335,258	330,658	343,342	338,744	351,738
Yeka	427,949	444,365	438,401	455,218	448,991	466,214	459,979	477,624
Bole	381,433	396,065	390,749	405,738	400,185	415,536	409,976	425,703
Addis Ababa	3,381,587	3,511,304	3,464,144	3,597,028	3,547,757	3,683,848	3,634,545	3,773,965

Production and attraction values explained in Table 12 above are the overall daily movements experienced by each sub city of Addis Ababa, However according to the 2017 Addis Ababa Transport Management Office Report, out of the total movements in Addis Ababa, 70 % are performed by walking and cycling, 26 % by public transport and 4 % by private cars. Even if the majority of the movements are performed by walking and cycling, there is no enough access of infrastructures and facilities for walking and cycling in the City. In addition in Table 12 above, it can observed that if population grows by a constant rate, trip production and attraction will be increased by yearly average growth rate of 2.39% and 2.41% respectively. Figure 19 below illustrates the projected trip production and trip attraction of Addis Ababa by sub cities.

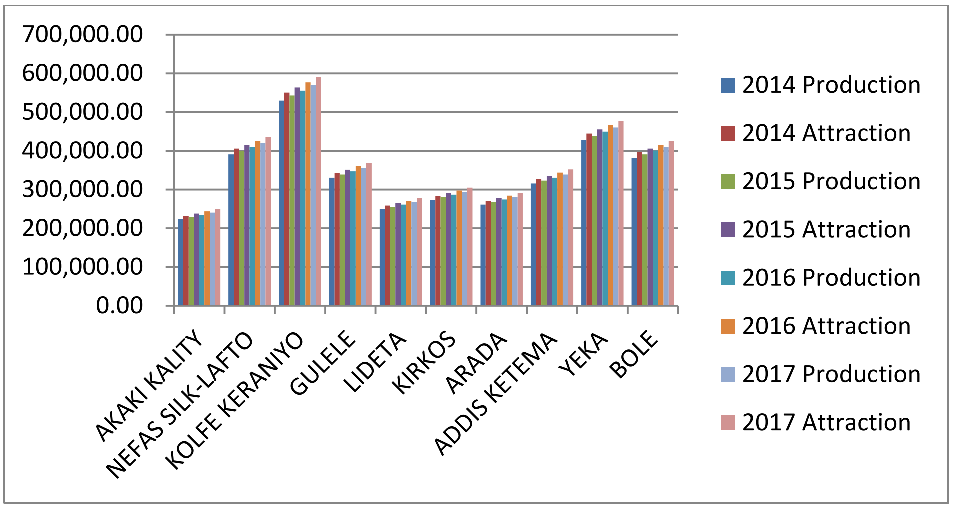


Figure 19: Trip Production and Attraction of Addis Ababa sub cities

Trip production and attraction are not exactly equal due to different reasons. As observed in Table 12 above, trip attractions are somewhat greater than trip productions and this is because some of the employed workers that were attracted to Addis Ababa did not necessarily originate within Addis Ababa, but travelled from the outskirts of the city. For example, employees may come from Sululta, Sendafa, Dukem, Bishoftu, Sebeta, and like others. So, it needs a factor to match the trip productions and trip attraction. In this regard, the average balancing factor (trip production/trip attraction) value of 0.963 was used considering that trip production is more reliable than trip attraction.

When analyzing the data regarding Akaki Kality as a case study in this research, demographic data, employment data, and number of students' are collected at woreda level and used as input in the specified Regression Equation. The daily trip productions and attractions under different reasons for the sub city were developed and used as reference for the verification of the reliability of the 2005's Urban Transport Study Equations. Table 13 below presents the Akaki Kality Sub-city trip generation results by trip purposes in 2016.

Table 13:Akaki Kality Trip generation Analysis out puts by trip purposes, 2016

	Trip Production					Trip Attractions				
Woreda	HBE	HBW	HBO	NHB	Total	HBE	HBW	HBO	NHB	Total
1	20,974	9,698	5,066	585	36,324	20,052	10,288	5,635	77	30,004
2	7,032	5,622	2,780	321	15,756	6,723	5,964	3,267	50	17,690
3	6,431	6,578	3,495	404	16,909	6,148	6,978	3,822	27	18,931
4	21,272	8,964	4,208	486	34,931	20,337	9,509	5,209	39	25,907
5	5,749	5,920	4,557	526	16,753	5,496	6,280	3,440	25	17,091
6	12,042	9,698	5,388	622	27,752	11,513	10,288	5,635	51	28,537
7	17,619	8,964	4,557	526	31,668	16,845	9,509	5,209	50	26,569
8	15,548	9,698	4,208	486	29,941	14,865	10,288	5,635	226	38,406
9	10,137	10,727	1,018	117	22,001	9,692	11,379	6,233	24	29,766
10	951	1,403	388	44	2,787	909	1,488	815	14	4,519
11	899	1391	388	44	2,723	859	1,475	808	13	4,433
Total	118,658	78,666	36,059	4,167	237,551	113,443	83,450	45,711	601	241,858
%	50	33	15	2	100	47	33	19	1	100

Where

HBE = Home-based educational trip;

HBW = Home-based work trip;

HBO = Home-based other trip; and

NHB = None home-based trip.

As resulted, the percentages of each trip purpose were: 50 % for home-based educational trips; 33 % for home-based work trips; 15% for home-based other purpose trips, and 2 % none home-based trips in the case of production; whereas in the case of attractions, 47 % were home-based educational trip; 34 % were home-based work trips; 18% were home-based other purpose trips, and 1 % were none home-based trips.

4.3.4 Trip distribution

In the four-step transportation forecasting model, trip distribution focuses on trip makers' origins and destinations to develop a "trip table", which is a matrix that displays the number of trips going from each origin to each destination. Trip distribution Analysis is performed by using gravity model, in which the trips between two zones are directly proportional to the number of trips produced in zone i and the number of trips attracted to zone j and inversely proportional to the distance between the two zones.

The equation can be written as follows:

$$T_{ij} = A_i \, B_J \, o_i \, P_j \, F(C_{ij})$$

Where

T_{ij} = trips between zone i and zone j;

o_i = production in zone i;

P_j =attraction to zone j;

A_i =balancing factor for origin I which is expressed as $1/\sum_{j=1}^{n}(\mathrm{Bj\ Pj\ F(Cij)})$;

B_J = balancing factor for destination j expressed as $1/\sum_{\square=1}^{\square}(\mathrm{Ai\ oi\ F(Cij)})$;

and

$F(C_{ij})$ = cost deterrence from zone i to zone j expressed as exp(-α t_{ij}) when assuming it as exponential function

Where

tij = travel time or distance (generalized cost from zone i to zone j); and

α = parameter to be calibrated

In the case of trips distributed from Akaki Kality sub- city, six destination nodes within Addis Ababa sub cities were selected and these were: Saris, Bole, Legehar, Megenagna, Autobus Tera, and Ayer Tena Taxi stations. Figure 20 below illustrates the selected six trip destinations sub-cities for trips generated in Akaki Kality sub-city.

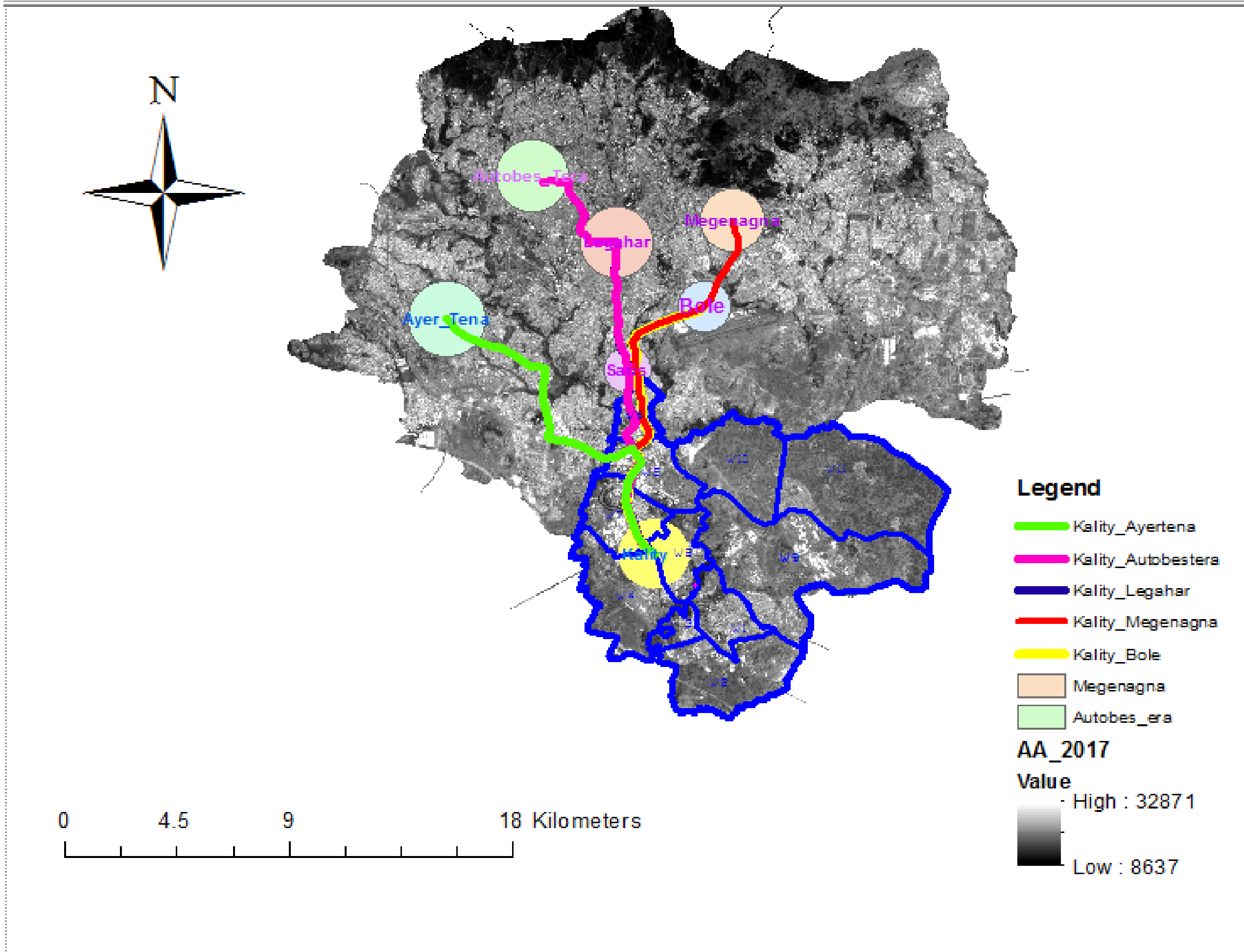


Figure 20. Location of selected six Stations from Akaki Kality sub-city.

By performing cordon surveys and data taken from the Addis Ababa Transport Authority public transport performance evaluation records, it was possible to estimate the base year trips originated from Akaki Kality sub-city and destined to Akaki Kality and then possible to calibrate constant parameters. By using the Gravity Model, data were analyzed and origins and destinations trip matrix was developed. As a result, travel times were used as deterrence functions for use in this study.For performing the double constrained gravity model calibration process, there are four required data inputs and these are:

i. Total zonal production and attraction values of the selected zones for the base year;

ii. Skim matrix as a function of travel time;

iii. Trip attractions and trip production ends (selected zones); and

iv. Average trip length and assumed as the average distances in between each selected zones.

Figure 21 below illustrates the structure of the Trip Distribution Model used in the study. Subsequently, Table 14 presents the trip productions and attractions of Akaki Kality and six selected destinations

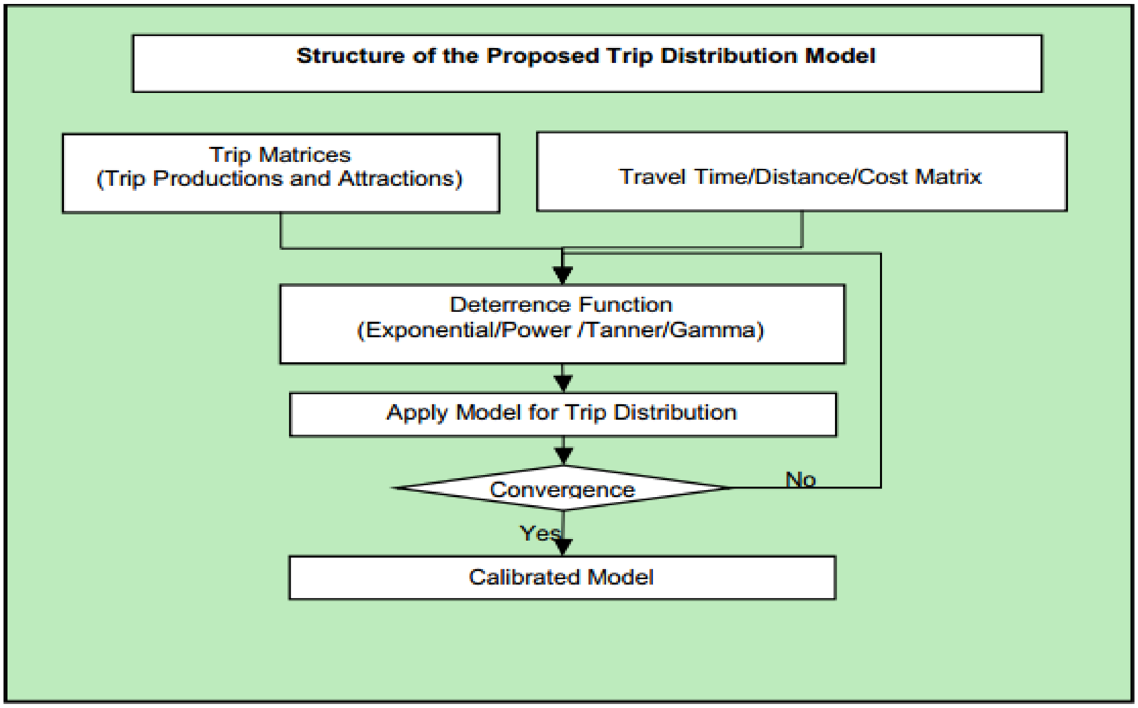


Figure 21: Structure of the proposed Trip Distribution Model

Table14: Trip production and Attraction of Akaki Kality and six selected destinations.

Zone	Attractions	Production
Kality	40,401	51,210
Saris	55,937	39,222
Bole	38,021	39,440
Legahar	62,675	58,498
Megenagna	35,156	40,481
Autobes tera	33,402	36,356
Ayer tena	17,260	17,645
Total	282,852	282,852

Here, the trip production and attraction values are taken from the Addis Ababa Transport Authority's Public Transport Daily Performance Evaluation Report and verified through this study by making cordon surveys at those selected traffic zones by the researcher. When checking the Akaki Kality sub city travel demand in respect of trip generation for year 2016, it was 234,709 in the case of trip attraction and 243,713 in the case of trip production. When calculating the trips made by public transport (26% of the total trip), it was about 61,024 and 63,365 in respect of trip generation and trip attraction.. From these 40,401's are attracted to Akaki kality from the six selected traffic analysis zones, and also 51,210's are produced from Akaki kality and distributed to these six selected traffic analysis zones. Table 15 presents the skim matrix used in gravity model calibration for trip distribution analysis.

Table 15: Skim matrix used in gravity model calibration for trip distribution Analysis

Skim matrix expressed by Average Travel time in minutes							
from/to	Kality	Saris	Bole	Legahar	Megenagna	Autobes tera	Ayer tena
Kality	6	15	20	22	30	40	35
Saris	15	5	12	10	20	30	30
Bole	20	8	4	15	5	30	45
Legahar	22	10	15	4	20	15	25
Megenagna	30	20	5	20	3	35	50
Autobes tera	40	30	30	15	35	4	28
Ayer tena	35	30	45	25	50	28	7

When dealing with the calibration process by using Microsoft Excel, there should be initial assumptions in guessing the Alpha parameter. Accordingly, using the input data for calibration and the assumed values of Alpha, the first trip matrix was developed which was the initial iteration. If the sum of the productions and attractions in the formulated trip are not matched with the target value, again go through the next iteration. By dealing with some iteration, if the calculated demand did not match the target value and also if the calculated trip length and estimated average trip length did not match, guess other values of alpha parameter and do the iteration again.

In this research, guessed Alpha values and the estimated average trip lengths along with the iteration stages and outputs are presented in Table 16 below.

Table 16: Gravity model calibration trials for alpha values

Frequency of Iterations	$\propto$ value	Estimated Average Trip Length (km)	Stage of Iteration	Calculated Trip Length (km)	Calculated Travel Demand and Target Travel Demand
1	0.300000	12.1	35	5.90	Not similar
2	0.200000	12.1	35	7.06	Not similar
3	0.100000	12.1	35	10.9	Not similar
4	0.083675	12.1	35	12.1	Similar
5	0.075000	12.1	35	12.78	Not similar
6	0.050000	12.1	35	14.96	Not similar

The balancing factor for production and attraction should one, unless the trips are unbalanced. Graphically, by plotting Alpha parameters in the Y-axis and travel time in the X- axis, Figure 22 was produced as presented below.

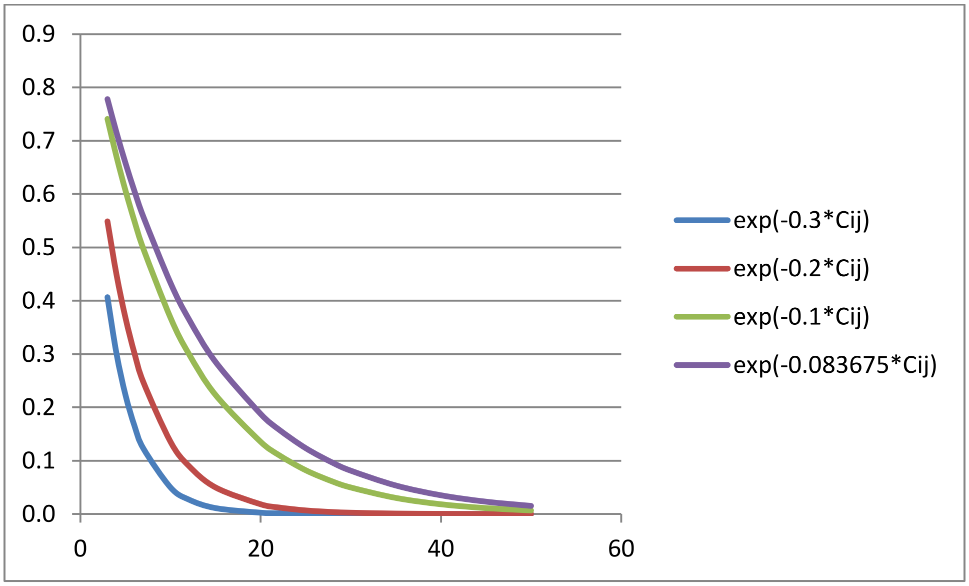


Figure 22: Gravity Model Calibration output

As observed in above exponential graph, as travel time increases the alpha parameter continually decreases. When dimensionally fix the graphs at the cost value (travel time) of five (5) minute, Figure 23 below is produced.

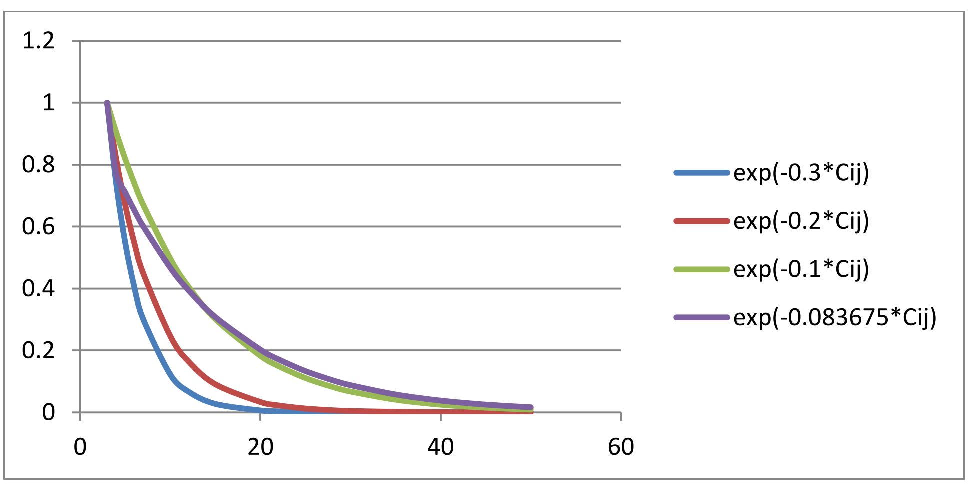


Figure 23: Gravity Model Calibration output after dimensioning

As observed from the above graph the one which has alpha parameter of 0.083675 is flatter than all the others which show as there are longer distance trips than the other three alpha values.

While dealing so the Origin and destination matrix for the seven zone of this research study area is formulated, and hence the trip distribution model is performed. Table 17 below presents the final trip distribution matrix of the study area.

Table 17: Trip distribution by public transportation for the selected study area, 2017

From	Kality	Saris	Bole	Lagahar	Megenagna	Autobes tera	Ayertena	Production
Kality	22,901	11,263	4,963	6,890	2,391	1,242	1,560	51,210
Saris	5,562	13,412	4,999	9,699	2,848	1,480	1,223	39,222
Bole	3,433	9,785	9,155	5,985	9,368	1,387	327	39,440
Legahar	4,340	12,373	5,452	22,461	3,992	7,276	2,604	58,498
Megenagna	2,031	4,897	11,502	5,381	15,129	1,247	294	40,481
Autobes tera	993	2,397	1,605	9,237	1,175	18,858	2,092	36,356
Ayer tena	1,141	1,810	346	3,023	253	1,912	9,160	17,645
Atraction	40,401	55,937	38,021	62,675	35,156	33,402	17,260	282,852

4.3.5 Modal split analysis

The third stage in the four-step transport demand modeling is determining the modal share for the trips in the transportation system. ‘Mode choice model estimation and application could be done either at disaggregate or aggregate zonal level where aggregate models seek to predict the zonal shares of trips by mode. Aggregate models are typically estimated using mode shares by origin-destination pair and average zonal demographics. Disaggregate models on the other hand are based on individual-level of data obtained from surveys. At the individual level, choice is discrete: a person picks one from a set of modal alternatives. Logit models are frequently estimated on individual-level data, and then forecasts are made based upon aggregate, explanatory variables’. (Tom V. Mathew. 2007)

‘The traveler’s choice for alternative transport modes is best explained by model applications of the Logistic Probability Unit, or Logit model. Logit model has the ability to model complex travelers' behaviors of any population size with simple mathematical techniques. The mathematical framework of Logit models is based on the theory of utility maximization.' (Tom V. Mathew. 2007)

'Logit models are generally classified into two main categories namely; binary and multinomial logit models. Binary choice models are capable of modeling with two discrete choices only, i.e. the individual having only two possible alternatives for selection; whereas, the multinomial logit models imply a larger set of alternatives.' (Tom V. Mathew. 2007)

Mostly, the modes of transportation with regard to infrastructural services available in Addis Ababa are road transport and rail transport. In road transport, the trips are made by either private vehicles (car) or public transport system like taxis and buses. In Addis Ababa, light rail transport system give services in some part of the city. According to the Addis Ababa Transport Authority Report of 2017, Walk, Bicycle, Motor Bikes, Bajaj, Lada taxi (Salon taxi), Private car, Taxi (Mini bus), Medium Bus (Higer), City Bus (Anbesa, Sheger, Aliance), public Bus, Services, and light rails are the means of transport in Addis Ababa.

In this research, the modal share of the trips for the selected study area with regard to public transportation system was analyzed. For the development of travel demand modeling, only the public transport means of, Taxi (Mini bus), City Bus (Anbesa, Sheger, Aliance), Medium Bus (Higer), and light rail were considered.

'There are four elements that are associated with the mode choice process; the decision maker, the alternatives, the attributes of alternatives and the decision rule' (Koppelman and Bhat, 2006). In general, the probability of an individual i selecting a mode n, out of M number of total available modes is estimated using the following equation as provided by Koppelman and Bhat (2006):

$$\boldsymbol{P}n = \exp(\boldsymbol{U}n) / \sum_{i=1}^{m} (\exp(\boldsymbol{U}m)$$

Where

Pn = the probability of choosing mode n from other m modes (m=1,2,3..);

Un = the utility function for mode n; and

Um = the utility function for other m modes.

Having the above utility function for mode choice probability, Logit models are classified into three and these are: Binomial (if there are two alternative mode choices), Nested, which allows a correlation between the utilities of the alternatives in common groups and Multinomial logit models which has many alternative modes in the choice. Using an average cost of traveling and their impedance matrices, the total number of trips of each mode is estimated. In this regard, descriptions are provided below.

i. **From Kality to Megenagna**: In 2009 E.C. (2016/17 G.C.), a survey was conducted by the Addis Ababa Transport authority. Under the survey, it was observed that there were 20 Higer buses with a capacity of 55 passengers and an average daily travel of four (4) transporting a total of 4,400 passengers. And three large buss (2 Anbesa bus and 1 Aliance bus) having a capacity of 60 and an average daily travel of four (4) transporting a total of 720 passengers. When calculating the percentage share for the two modes, it was estimated at 86% for medium Bus (Higer) and 14% for Large Buses. So, the available public transport modes are Large Buss and Higer Bus in which the cost for traveling is Birr 4 and Birr 5 respectively.

   However, if taxi transportation services were allowed on the link, passengers' interests will vary depending on travel time and travel cost. In this regard, by accounting for these two inputs, total costs were calculated and the ratio of mode contribution was estimated. Then using the logit model, the percentages of mode choice were estimated as follows:

   P (large buss) = EXP $(-GCR_{LB})$ / (EXP $(-GCR_{LB})$ + EXP $(-GCR_{MB})$ + EXP $(-GCR_{T})$).

   Where, GCR is generalized cost ratio for large Bus, medium Bus, and taxi.

   By using the above equation, mode share was calculated at about 28.2% for taxi, 37.1% for Medium Buss, and 34.7% for Large Bus. Rail transport mode was not considered since there is no rail link in the area.

ii. **From Kality to Bole:** The available public transport modes along this route are taxis, Higer buses and large buss with trip costs of Birr 10,, Birr 5 and Birr 4 respectively. Using the same method as above, the percentage share of Taxi, Medium Buss, and Large Bus were calculated at 27.7%, 35.7%, and 36.6% respectively. Because there are no rail transport mode in the link, LRT was not included in the modal split analysis.

iii. **From Kality to Ayer Tena:** In this link, the available transport mode is only Higer bus. According to the Authority's Report, there are 14 Higer buses assigned on the route. Therefore, Higer Bus has 100% modal share along this route. But, if there was the situation of allowing taxis and large buses on the route, there would be mode preferences for passengers based on utility with regard of travel time and travel cost. If this was the case, the percentage share of the modes in the link would have been about 28.7for Taxi, 35.1% for Medium Bus, and 36.2% for Large Bus. Because there are no rail transport modes in the link, LRT was not included in the modal split analysis.

iv. **From Akaki Kality to Saris, Legehar, and Autobus Tera:** In these destinations, the available transportation modes were Medium Bus, Taxi, Large Bus, and LRT. To understand the percentage of mode choice along the corridors, intensive traffic counts, travel time measurements, speed measurements and travel costs were recorded in respect of each mode. This study dealt with the previous researches; for instance, Asaye Melaku who did his Master's Thesis on travel demand analysis on AALRT East – West corridor of Addis Ababa which is part of this study. According to him, the final percentage contribution of each mode was calculated at 16.4%, 47.7%, 10.0%, and 25.9% for Medium Bus, Taxi, Bus, and LRT respectively. But according to this case study, the percentages of mode shares were calculated at 19.6% for Medium Bus, 39.3% for Taxi, 17.8% for Large Bus, and 23.3% for LRT.

Generally, in the links that connect Akaki Kality to six selected destinations, the most frequently used mode was Bus. This is because the Akaki Kality sub city is located at the periphery of Addis Ababa, and most of the residents are low income groups. Unlike travel time and comfort, bus transport is a more preferable mode for such society with regard to travel cost and loading capacity. 'Peripheral zone residents, who are public or private company employees with large family size, have higher tendency of choosing bus over taxi.' (Mintesnot and Shin-ei (2007).

4.3.6 Traffic Assignment

Traffic management is the last step of the four step travel demand modeling process. In this step, the trips in the traffic system are to be loaded in their respective infrastructural networks. There are different types of Traffic Assignment techniques mostly used in urban transport planning and these are:

i. '**All or Nothing Assignments**: This type of assignment technique assigns all the traffic between origin and destination pairs based on the least cost path and does not consider the alternative routes available for the trip. Similarly, traffic is assigned to links without considering the capacity of the links and congestion level. Because road network optimization is not performed, this type of assignment technique has limitations. It ignores the fact that the cost on the links are depending on the volume, and hence if there is high volume on the link and congestion happened, multiple paths may be used. Travel time is a fixed input and does not vary depending on the congestion on a link. However, this model may be reasonable in sparse and uncongested networks where there are few alternative routes and they have a large difference in travel cost. In fact, this model's most important practical application is that it acts as a building block for other types of assignment techniques.' (Ortuzar &Willumsen, 2011)

ii. **Capacity Restrained Assignment:** This is also known as Incremental Traffic Assignment Technique. In this type of assignment technique, trip matrices are loaded in the paths and network speeds are updated at the end of the assignment. This method of Assignment is more dependent on the characteristics of the network and also it considers speed-flow relationships for the links. To be more accurate in the assignment process, it is recommended to divide the networks into smaller portions.

iii. **Incremental Assignment:** This is a process in which fractions of traffic volumes are assigned in steps. For each step, a fixed proportion of total demand is assigned based on all-or-nothing assignment. After each step, link travel times are recalculated based on link volumes. When there are many increments used, the flows may resemble an equilibrium assignment. However, this method does not yield an equilibrium solution. Consequently, there will be inconsistencies between link volumes and travel times that can lead to errors in evaluation measures. Also, incremental assignment is influenced by the order in which volumes for zone to zone pairs are assigned, raising the possibility of additional bias in results.

iv. **STOCH Assignment**: This type of traffic assignment distributes trips between zones of origin-distribution pairs among multiple alternative paths that connect the pairs. The proportion of trips that is assigned to a particular path equals the choice probability for that path, which is calculated by a Logit Route Choice Model. Generally speaking, the smaller the travel time of a path compared with the travel times of the other paths, the higher its choice probability would be. STOCH Assignment, however, does not assign trips to all the alternative paths, but only to paths containing links that are considered "reasonable." A reasonable link is one that takes the traveler farther away from the origin and/or closer to the destination. The link travel time in STOCH assignment is a fixed input and is not dependent on link volume. Consequently, the method is not an equilibrium method.

v **User Equilibrium Assignment**: This is based on the principles of no driver can unilaterally reduce his travel costs by shifting to another route. If it is assumed that drivers have perfect knowledge about travel costs on a network and choose the best route.

vi. **System Optimum Assignment:** This is based on the principle, which states that drivers cooperate with one another in order to minimize total system travel time. This assignment can be thought of as a model in which congestion is minimized when drivers are told which routes to use. Obviously, this is not a behaviorally realistic model, but it is useful to manage the traffic to minimize travel costs and therefore achieve an optimum social equilibrium. Figure 24 below presents the Addis Ababa Road Network Map and the selected stations in the study.

Figure 24: Addis Ababa Road Network Map and Selected stations in the study.

In this research, trip assignment was done on the links from Akaki Kality to the six selected destinations. Since in this research there are no distinct alternative routes for making trips from Akaki Kality to the four destinations (Bole, Megenagna, Ayer Tena, Saris), All or Nothing Traffic Assignment Technique was used. Figure 25 below shows the links that connect the Akaki Kality sub city and the six selected destinations.

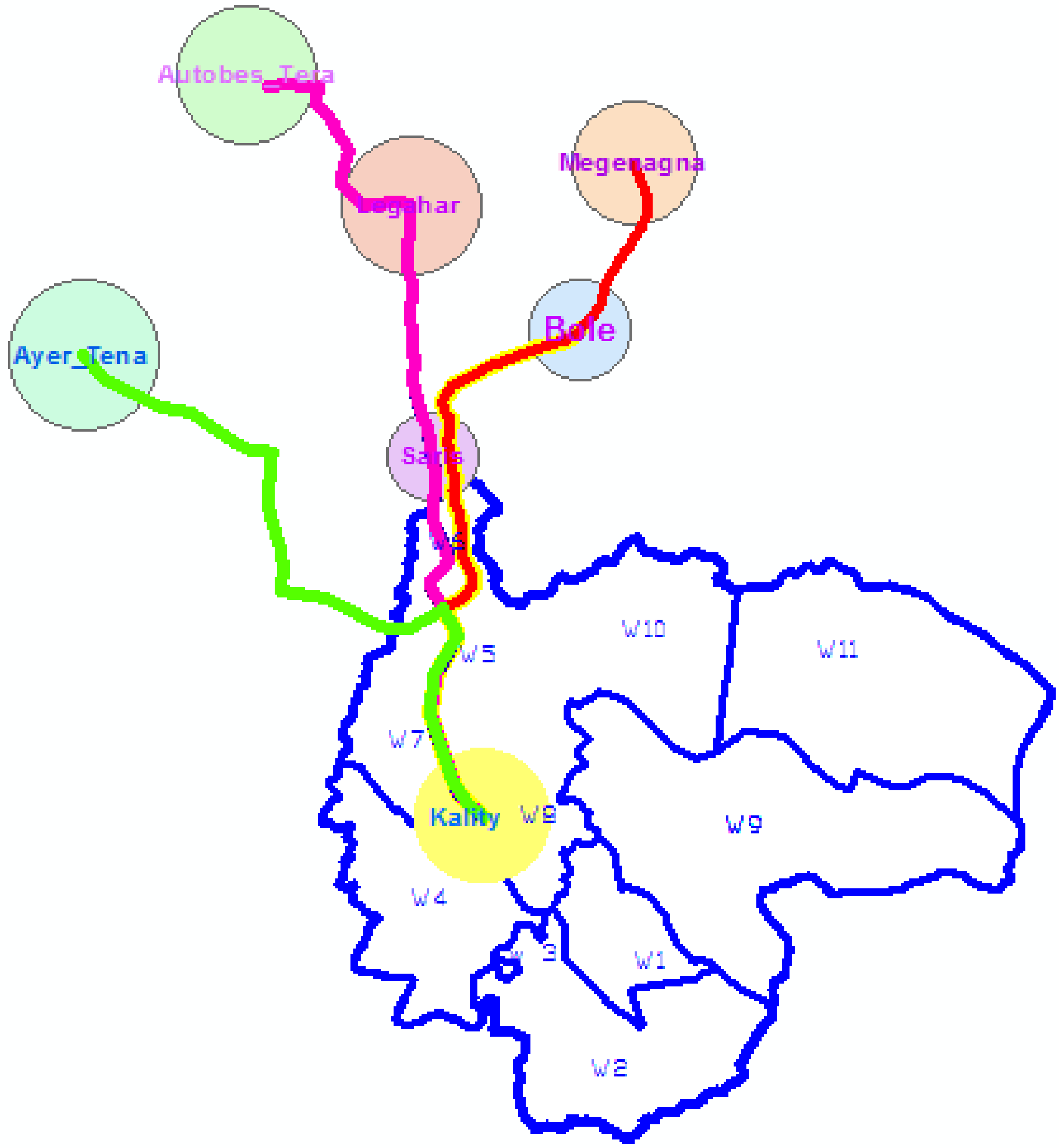


Figure 25: Links that connect Akaki Kality sub city and its six selected destinations

Along the link from Akaki Kality to Legehar, there are three alternative routes in which they vary by their travel time, travel cost, and travel distance. So, the traffic assignment has followed mathematical procedures which were based on the link performance functions. This is the mathematical descriptions of the relationships between travel time and link volume. Figure 26 below shows the alternative routes on the link from Akaki Kality to Legehar.

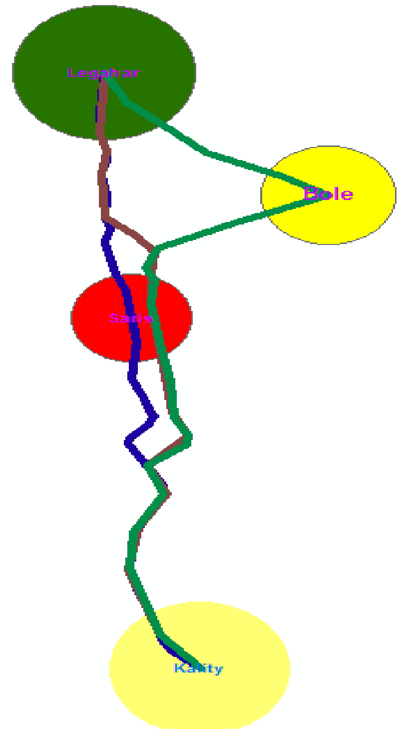


Figure 26: Alternative routes on the link from Akaki kality to Legehar

To deal with the traffic assignment process using mathematical equation, the overall road characteristics and specific link attributes need to be analyzed. These attributes are link volume, link capacity, free flow speed, congestion level (LOS), free flow time, congested link travel time, synchronization of the vehicle fleets on the links (PCE), geometric characteristics, conditions of the links.

However in this research, the assignment technique performed was only trip assignment; so the daily trips from Akaki Kality to Legehar and Autobes Tera were to be distributed to the three alternative routes based on the their respective travel time and travel fare. From the trip distribution analysis, the total trips originated and designated to Autobes Tera and Legahar was calculated at 18,153.

By considering the origin is Akaki Kality and destination is Legehar, the travel times for part of the link which passes through Saris, Kadiso, and Bole were 35 minutes, 25 minutes, and 30 minutes respectively. These values were derived from the average of repeated measurements in travel times.

Having this, the proportion of trip makers to choose which links they use to transit was calculated based on their respective travel time. The following assumptions were considered: Ts is travel time through Saris; Tk is travel time through Kadisco, and Tb is travel time through Bole. Based on the assumptions above the following relationships were developed.

i. In the case of the Link from Akaki Kality to Legehar which passes through Saris, the Proportion of trip = (1/ Ts) / **(**1/Tk+1/Ts+1/Tb**).**

   Thus, (1/35)/**(**1/35+1/25+1/30**)** = 0.28. Therefore, the total daily trip on this link is 0.28*18,153= 5,083. This means that about 5,083 passengers use the Akaki Kality-Saris-Legehar route out of the total 18,153 trips generated in the Akaki Kality sub-city..

ii. In the case of the Link from Akaki Kality to Legehar which pass through Kadisco, the Proportion of trips = (1/ Tk) / **(**1/Tk+1/Ts+1/Tb**).**

   Thus, (1/25)/ **(**1/35+1/25+1/30**)** = 0.39 therefore, the total daily trip on this link is 0.39*18153=7,080. This means that about 7,080 passengers use the Akaki Kality-Kadisco-Legehar route out of the total 18,153 trips generated in the Akaki Kality sub-city.

iii. In the case of the Link from Akaki Kality to Legehar which pass through Bole, Proportion of trip = (1/ Tb) / **(**1/Tk+1/Ts+1/Tb**).**

   Thus, (1/30)/ **(**1/35+1/25+1/30**)** = 0.33. Therefore, the total daily trip in this link is 0.33*18153=5,990. This means that about 5,090 passengers use the Akaki Kality-Saris-Legehar route out of the total 18,153 trips generated in the Akaki Kality sub-city...

Figure 27 below illustrates the trip assignment results from Akaki Kality to the six selected destinations, 2016

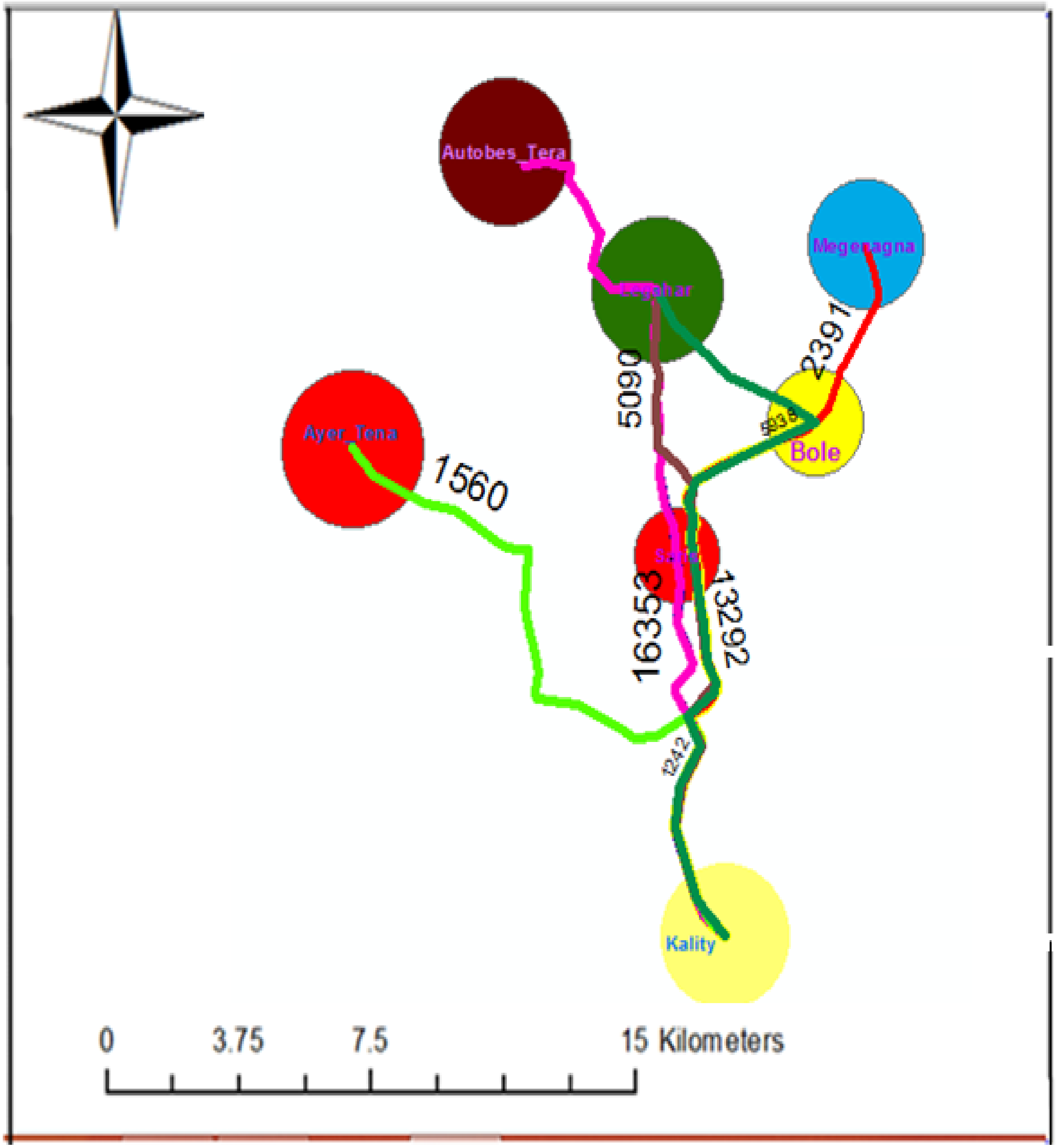


Figure 27: Trip Assignment Results from Akaki Kality to the six selected Destinations, 2016.

CHAPTER FIVE

5. RESULTS AND DISCUSSIONS

5.1. Land use expansion analysis results and forecasting

5.1.1. Physical urban expansion

Addis Ababa has been a sprawling city, since it originated in 1886 and it has continued sprawling due to its unstructured and unplanned nature. According to Tilahun (2014), Addis Ababa had a number of plans by noticeable architects and town planners between 1936 and 1986 but not properly materialized. This unsuccessful planning history of the city is reflected in its development, which has largely been characterized by spontaneous growth. 'In 1920, the city was bounded within an average radius of 3.25 km which has now extended to about 25 km.' (Fekadu,2014)

According to the findings of this research, from the period 1988 to 2000 the city's built-up area showed a tremendous increase of 47.7% resulting from the total area of 109 km^2 in 1988 to 161 km^2 in 2000. During that time, the Addis Ababa Master Plan (AAMP) had given consideration for the development of one city main center go together with six sub-centers in the intermediate zones and three minor sub-centers for the expansion areas. However, the Master Plan was revised in 2001 and due to this from the period 2000 to 2011, the city's built-up area showed an increase of 50.3% from the total area of 161 km^2 in 2000 to 242 km^2 in 2011. During the latter period, the city has been undergoing horizontal expansion as the major development in its history. From the period 2011 to 2017, the city's built-up area increased by 37.6% from the total area of 242 km^2 in 2011 to 333 km2 in 2017. During this time, the horizontal expansion growth rate had relatively decreased. This was because the governments had taken immediate actions for illegal settlement and provided opportunities for condominium residential dwellings at different sites which resulted in adopting the " in field" type of urban expansion.

Recently, Ethiopia was ranked by the International Monetary Fund (IMF) among the five fastest growing economies in the world, after a decade of continuous expansion during which the real Gross Domestic product growth (GDP) averaged 10.8% per annum. As a result, Addis Ababa is exhibiting significant changes associated with this. This includes the city's first light rail network that is part of a plan to make the Ethiopian capital city's public transport system going to be sustainable, by shifting the transportation system from the current dependence on minivan taxis and buses.

The fast rate of horizontal expansion and urbanization has also needs for huge economical and capital intensive infrastructural service development. Especially, constructions of transportation infrastructures are needed to address the needs for the scattered population's transportation demand. In addition, there are households settled at the outskirts including residents of low-income people that need transportation services but cannot afford to buy private cars. This is the other concern to be considered in providing access of transportation service for such scattered residents. On the other hand, this is an opportunity to the existing public transportation service providers.

5.1.2. Population forecasting

The population forecast for Addis Ababa was done using base-year data from the Central Statistics Agency of Ethiopia, 2007 and using inter-censual survey which was carried out in 2012 The CSA has provided population data on Kebele level in total and by sex group for the years 2014 – 2017. Using these population data projections from the two sources, the required population was projected for the years 2018 – 2040.

As observed from the projection, Addis Ababa has a high population growth rate which results in vast population expansion, price change and economical inflations. Since transportation demand is one part of the city's service sector and has proved so in the rapid change, although not yet met the required demand. But this rapid change may create divisions between the wealthy at the top and the needy at the bottom. Due to this reason, the low income population group that has settled at the periphery demanded the extension of transportation services reaching their residential areas.

As a result of rapid horizontal expansion and the unplanned growth, Addis Ababa is now provoked with increasing demand for travel because of the rapid growth of population of the city that has put great pressure on the demand for urban open spaces. To accommodate this transportation demand, exertions are being made by the city government to integrate the peripheral areas of the city, which is resulting in speeding up the sprawl of the built-up area of the city. But , due to limitations to provide the required the road infrastructure at the peripheries, the residents have no access to the public transport as the demand directs. Even there is inadequate and no appropriate pedestrian walk ways and limited compatible foot paths, this also might lead to awkwardness of people on their daily movements.

According to the International Labor Organization (ILO), the age group between 15– 65 are productive worker group, which are expected to accounts for 71.89 percent of the total population. Having this information, out of the total age group of Addis Ababa 10.21 % s are below the age of 5 years and they don't utilize transportation infrastructure, and 89.79 percent of the population is potential user of transportation infrastructure. Figure 28 below graphically illustrates the estimate of population projection of Addis Ababa city for the coming years.

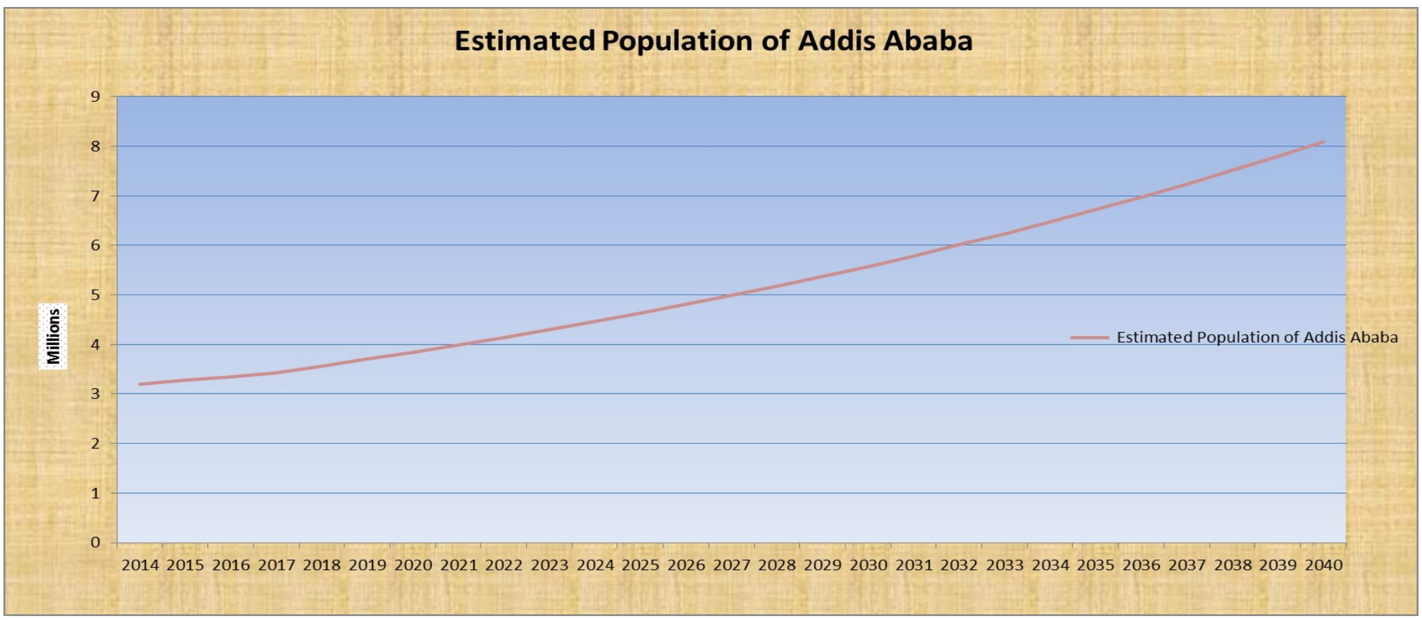


Figure 28: Population forecast of Addis Ababa for the coming years

5.2 Transportation demand analysis results and forecasting

5.2.1. Demand Forecasting

According to the ERA Urban Transport Study, 2005 Report, in Addis Ababa, the Average daily movement per person is 1.08.Similarly when dealing the research, the average daily trip making per person in 2017 was 2.26 (total population / total daily trip). This shows that the trip making characteristics of the Addis Ababa residents have been increasing from year to year by a yearly average of 10% due to social and economic activity requirements. Thus in 2040, the population of Addis Ababa is expected to be about 8 million and each having an average daily trip making of 4.5 per person. In this respect, one has to bear in mind that how much supply (infrastructural service and vehicle fleets) are required for accommodating this demand? Clearly, it is the hot issue that everybody who are involved in the land use and transportation planning sector should think of it.

With regard to Akaki Kality sub-city, the trip making characteristics of the passengers is more of work purpose trip, in which more of the travelers move from their peripheral residential places to the major central business district of Addis Ababa, including the six selected destinations analyzed in this research. The trips are made towards the center in morning and vice versa in the evening. From the study, it was observed that as there was no balance between origins and destinations during that independent time period.

On the other hand, since the urban expansion type of Addis Ababa is green field horizontal and toward the periphery and Akaki Kality is part of this, future settlement is more than the expected This is manifested by the numbers of condominium sites, residential blocks, industrial, and retail services that have been constructed and are under construction. This forthcoming residential settlements, industrial developments, and retail services will raise the need for high urban transportation services.

5.2.2. Supply forecasting

5.2.2.1. Transport network forecasting

According to Ethiopian Roads Authority Urban Transport Study of Addis Ababa, 2005 Report, the road coverage in Addis Ababa was about 7% of the total land use of the city, which was below the standards of developed nations which about 20-30%. To achieve the standard road coverage, construction of new roads and up grading the existing gravel and earth coated roads are required by allocating more financial resources and by developing a rational master plan. In this regard, the 2000-2010 city development plans was part of this which was aimed at to meet the objective of addressing the road coverage by increasing to 15%. Table 18 below shows the road coverage forecast of the Addis Ababa City.

Table 18: Road coverage forecast of the Addis Ababa City

Year	1998	1999	2000	2001	2002	2003	2004	2005	2010	2014	2016	2040
Paved road (km)	681	684	688	698	716	756	778	817	1280	1384	1446	2853
Gravel road(km)	1184	1223	1235	1266	1286	1300	1368	1383	1534	3230	3374	6658
Total road(km)	1865	1907	1923	1964	2002	2056	2146	2200	2814	4614	4820	9511
Percentage increment	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2010	2010-2014	2014-2016	Yearly Average increments	
Paved Road	0.4	0.6	1.5	2.6	5.6	2.9	5.0	11.3	2.0	2.2	3.4	
Gravel Road	3.3	1.0	2.5	1.6	1.1	5.2	1.1	2.2	27.6	2.2	4.8	
Total Road	2.3	0.8	2.1	1.9	2.7	4.4	2.5	5.6	16.0	2.2	4.1	

5.2.2.2. Vehicle fleet forecasting

Vehicle fleet forecasting of the Addis Ababa City was done in the previous ERA Urban Transport Study, 2005. During that time, the average growth rate and the number of vehicles for the year 2020 was estimated using five years registered vehicles data taken from Ethiopian Road Transport Authority. Even though it was stated in the Report that the estimate was very conservative but it didn't correspond to what the real situation is. In this research, the average vehicle growth rate specified in the previous research was used to estimate the number of vehicles for the year 2016 and compare with the actual number of vehicles registered in Addis Ababa in the same year. But the actual data was three times more than the estimated values. Especially, the number of private cars and commercial vehicles has increased dramatically that do not significantly play in serving the mass public passengers. On the other hand, it exacerbates the problem of congestion and environmental pollution in the city. Thus, according to the Addis Ababa Transport Authority Report (2016), the total number of vehicles was about 480,108. When making comparative analysis with the ERA Urban Transport Study estimate for the year 2016, the average growth rate of registered vehicles in Addis Ababa was found as 13.5% whereas, in the study of ERA, the average growth rate was 4.5%. Using this Average growth rate, the total numbers of vehicles in Addis Ababa for year 2020 and 2040 were estimated at 740,976 and 2,741,611 respectively. This needs thorough attention as to how many vehicles are going to be added yearly in the transport network of Addis Ababa for the coming years and think how the vehicle flows could be influenced by the absence of adequate road infrastructure. Thus, volume to capacity Ratio going to reach maximum and level of service is considered to be low. Table 19 below shows vehicle forecasts for Addis Ababa City the years 2020 and 2040..

Table 19: Vehicle fleet forecasts for Addis Ababa

	From the ERA urban transport study, 2005 Report, the AGR is 4.5%								In this research the AGR is 13.5%		
Vehicle Type	1993	1994	1995	1996	1997	AGR (%)	2016 estimated	2020 estimated	2016 real	2020 forecast	2040 forecast
Taxi	10,991	12,040	13,089	13,536	13,665	5.59	21,044	25,906	20,913	82,899	306,727
Private Car	44,667	47,234	50,130	52,944	54,336	5.02	83,677	98,823	175,290	316,234	1,170,064
Commercial	12,238	13,107	14,062	14,833	15,299	5.74	23,560	81,849	233,672	261,917	969,092
Governmental	6,220	6,341	6,746	6,821	6,916	2.69	10,651	12,019	28,792	38,461	142,305
public association	1,378	1,455	1,505	1,529	1,555	3.07	2,395	2,360	3901	7,552	27,942
Aid organization	3,065	3,239	3,434	3,472	3,612	4.19	5,562	6,387	12,847	20,438	75,622
AU	181	193	197	198	203	2.91	313	272	436	870	3,220
Diplomatic	754	839	929	935	984	6.88	1,515	2,112	2,619	6,758	25,006
UN	853	939	993	1,006	1,035	4.65	1,594	1,827	2,610	5,846	21,632
Total	80,347	85,387	91,085	95,274	97,605	AGR is 4.5	150,312	231,555	481,080	740,976	2,741,611

In this research, it was assumed that the number of vehicles which were involved in public transportation will be growing at the same growth rate with total vehicles and this will make operations difficult in the absence of appropriate policy and regulatory interventions.

5.3 Forecast the interactions between land use and transportation demand

It is clear that living in low density scattered and mixed land use zone was the major experience of most developing cities including Addis Ababa. These results in long motorized vehicle trips, more travel distances, and longer travel times for trip makers. The reasons for such transportation problem are: the travelers' behavior on trip making; spatial characteristics of the residential areas; environment, or socio-economic and demographic differences among the residents. On the other hand, higher density areas having well planned and distinguished land use zones are characterized in less car use, more public transport usage (mass rapid transit), and use more walking mode in making daily trips. In addition, attitudes, lifestyles, perceptions and preferences towards transportation mode and economical capacity of the passengers are the major effects on the land use type and transportation systems inter dependent.

By analyzing the data, adopting different equations, models, and calibrated parameters; it was found that the population of the city will increase by 3.8% per year while the physical built up area will increase by 3.2% per year. On the other hand, due to high economic growth and peoples' interests on private cars, the number of vehicles will increase by 13.5% per year with average urban mobility increase of 10 % per year. However, the road network coverage is growing yearly by an average of 4.1% which can't meet the increased transportation service demand and vehicle fleets. Thus, all result in continuous day-to-day transportation problems of the city; like congestion, traffic accidents and environmental impacts. Figure 29 below illustrates the urban land use change and transportation demand interactions.

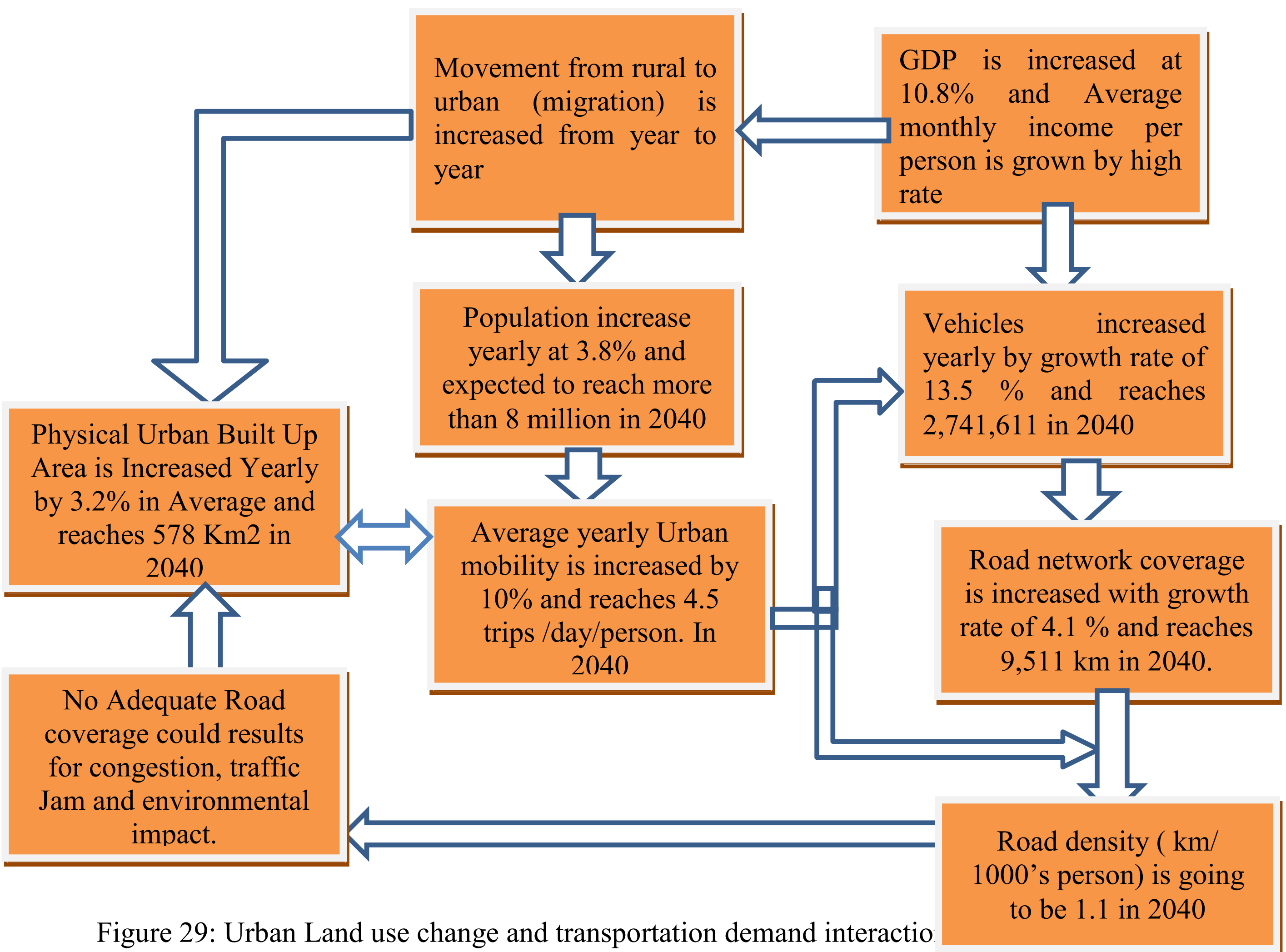


Figure 29: Urban Land use change and transportation demand interactio

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

In Addis Ababa, there are high physical horizontal expansions which are explained by scattered and sprawled settlements in the peripherals of city. Thus due to this expansion and land use change, there is a big gap between public transportation demand and supply. As a result of these phenomena, the service standard of the current transportation system is going down. Some residential located at the periphery are far away from the main roads and these expanded areas of the city are not fully served by public transportation. The expansion of the city, increasing population size coupled with the economic growth has required corresponding transportation services for the increasing mobility needs of the people. there is no well coordination and cooperation between the land use and the transport sectors in Addis Ababa. Thus, lack of integration between land use and transportation planning has resulted in disproportions between travel demand forecasting and land use developments in different sub-cities of Addis Ababa.

Generally, the land use type of Addis Ababa is dominated more by residential; whereas in Akaki Kality sub-city, the majority of the area is covered by environmental features (forests, rivers, bare lands, wet lands, and gorges and valleys). When passenger transport system is considered, the residents are more interested to have auto and taxi driving licenses than owning other higher driving licenses. Thus indicates that in the coming years, the residents are determined to own automobiles without considering the future transport system problems. The type of urban expansion in most of the Addis Ababa sub cities follow centroid in fill type, whereas it is leap frogging green fill type for Akaki Kality sub city which is not easy to provide transportation services for the different settlements.

6.2. Recommendations

- The physical horizontal expansion, economic advancement and rapid population growth in Addis Ababa results in many transportation service problems like: congestion, inaccessibility and unsafe conditions for the transport users. Thus, urgent attention should be given in solving these problems by organizing the sectors by introducing and using scientific innovations and technological advancements in the system. Therefore, a great effort should be made by the responsible agents in achieving technology transfer in mass transportation system. In this regard, buses and light rails are very efficient in terms of land use because they always use networks which could be needed for access through traffic requiring less extra spaces.
- It is clear that public transport has high passenger carrying capacity requiring little spaces. In this regard, mass public transportation modes such as Light Rail Transit (LRT) which is currently operating in Addis Ababa, Bus Rapid Transit (BRT) and others should be encouraged to operate in urban centers of Ethiopia.
- Migration from rural areas to Addis Ababa is a direct cause of travel demand inflation from year to year.
- It is better if appropriate zoning policy is implemented. In this regard pertinent policies need to be formulated and implemented.
- Addis Ababa is the largest city in Ethiopia, Which is expanding at the expense of other cities in the country. Therefore, the required economic and social opportunities should be provided to other urban centers in the country to balance population growth and transportation services availabilities.
- Generally, the following recommendations are forwarded for solving the future transportation system problems in Addis Ababa City as well as in Akaki Kality sub city:

- **Short term solutions, related to traffic management systems**
  - ✓ Diversion of permission for taxi destination at peak hour by policemen certification;
  - ✓ Shift start and end time of work for some institutions, offices, etc.;
  - ✓ Permit for using alternative routes for minimizing traffic congestion;
  - ✓ Promoting private car owners to give ride for other passengers, especially at peak hour;
  - ✓ Promoting walking habit for passengers;
  - ✓ Restrict the operation of heavy vehicles during peak hours, especially in the morning and afternoon hours; and
  - ✓ Create integrated supervision of the traffic system to reduce congestion and accidents.
- **Long term solutions, related to future plan**
  - ✓ Organize and coordinate transportation and other infrastructure planning and implementation;
  - ✓ Develop and implement zoning policy, for the land use system and reduce the travel demand and travel length by providing amenities and services ;
  - ✓ Design and implement intelligent transport system. For example, build and promote Bus Rapid Transport system along with giving priority to mass transportation services on major roads and intersections which would ensure enhanced, efficient and high level of service. Also ensure bus, taxi, rail terminals and freight centers convenient to users.
  - ✓ Assess and improve the condition of existing roads, traffic symbols and pavement markings;
  - ✓ Facilitating and encouraging modal shift to non-motorized transport options through providing Bi cycle networks, especially in periphery of the city.
  - ✓ Discouraging private car ownership through policy interventions and making improvements in the vehicle technology.

6.3 Future research directions

Base on this study, the following research areas are proposed:
This thesis was limited to studying the interactions between land use change and public transportation demand in Addis Ababa City, specifically in Akaki Kality sub-city. There for Future researches can incorporate all modes of passenger transportation including; private car users, pedestrians, light rail transportation users, visitors and other transport users. Thus the interactions between each of mode types with Land use change should be studied.

The case study is specific to Akaki Kality sub city and on other six major destinations. So it is possible to study this issue in other parts of Addis Ababa.

The Trip Generation Model equations in this research were adoptions from the UTS, 2005 study. So the future studies can develop their own trip generation model by using the latest modeling software.

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APPENDEX

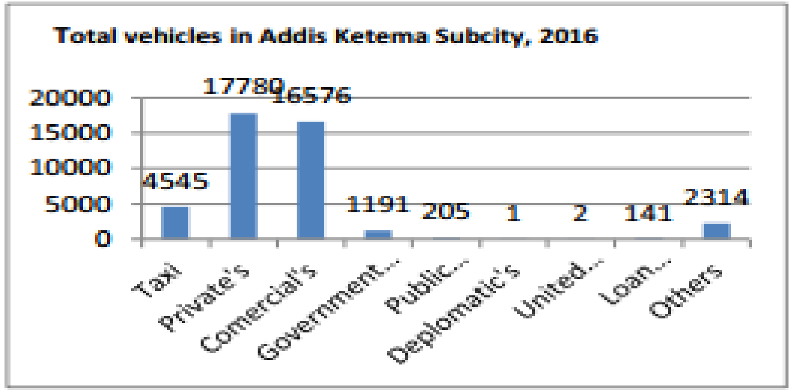
Appendex A: Population forcast of Addis Ababa.sub-cities

	Year	AKAKI KALITY	NEFAS SILK-LAFTO	KOLFE KERANIYO	GULELE	LIDETA	KIRKOS	ARADA	ADDIS KETEMA	YEKA	BOLE	Total
Base Year	2014	211380	368883	500163	312096	235246	258035	246680	297793	404336	360387	3194999
	2015	216538	377892	512369	319712	240989	264337	252705	305058	414212	369189	3273001
	2016	221759	387017	524729	327426	246805	270721	258808	312414	424217	378104	3352000
	2017	227182	396486	537561	335434	252842	277346	265141	320053	434599	387355	3433999
Projected	2018	235815	411552	557988	348180	262450	287885	275216	332215	451114	402074	3564491
	2019	244776	427191	579192	361411	272423	298825	285675	344839	468256	417353	3699942
	2020	254077	443425	601201	375145	282775	310180	296530	357943	486050	433213	3840539
	2021	263732	460275	624047	389400	293521	321967	307798	371545	504520	449675	3986480
	2022	273754	477765	647761	404198	304674	334202	319495	385664	523691	466762	4137966
	2023	284157	495920	672375	419557	316252	346901	331635	400319	543592	484499	4295209
	2024	294955	514765	697926	435500	328270	360084	344238	415531	564248	502910	4458427
	2025	306163	534326	724447	452049	340744	373767	357319	431321	585690	522021	4627847
	2026	317797	554631	751976	469227	353692	387970	370897	447711	607946	541858	4803705
	2027	329874	575707	780551	487058	367132	402713	384991	464724	631048	562448	4986246
	2028	342409	597584	810212	505566	381083	418016	399621	482384	655028	583821	5175723
	2029	355420	620292	841000	524778	395565	433900	414806	500714	679919	606007	5372401
	2030	368926	643863	872958	544719	410596	450389	430569	519742	705756	629035	5576552
	2031	382945	668330	906130	565419	426199	467503	446930	539492	732574	652938	5788461
	2032	397497	693726	940563	586904	442394	485269	463914	559992	760412	677750	6008423
	2033	412602	720088	976305	609207	459205	503709	481542	581272	789308	703504	6236743
	2034	428281	747451	1013404	632357	476655	522850	499841	603361	819301	730238	6473739
	2035	444556	775854	1051914	656386	494768	542718	518835	626288	850435	757987	6719741
	2036	461449	805337	1091886	681329	513569	563341	538551	650087	882751	786790	6975091
	2037	478984	835940	1133378	707219	533085	584748	559016	674791	916296	816688	7240145
	2038	497185	867705	1176446	734094	553342	606969	580258	700433	951115	847722	7515270
	2039	516078	900678	1221151	761989	574369	630034	602308	727049	987258	879936	7800850
	2040	535689	934904	1267555	790945	596195	653975	625196	754677	1024773	913373	8097283

Appendex B Number of Registerd vehicles in Addis Ababa sub city,

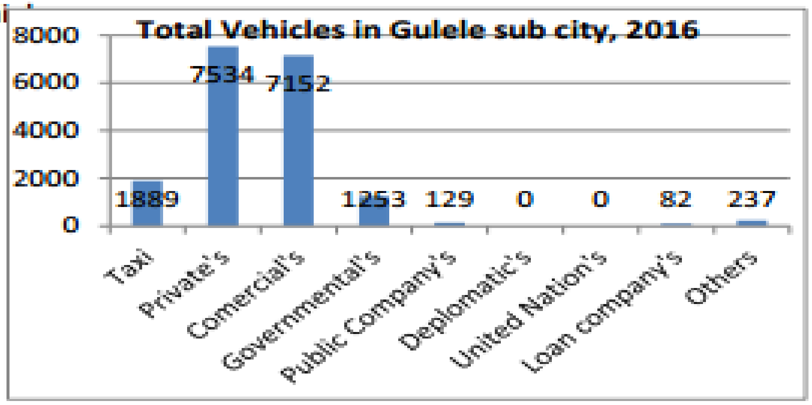
Addis Ketema subcity

type of vehicle	Total No. Vehicle
Taxi	4545
Private's	17780
Commercial's	16576
Governmental's	1191
Public Company's	205
Diplomatic's	1
United Nation's	2
Loan company's	141
Others	2314
Total	42755



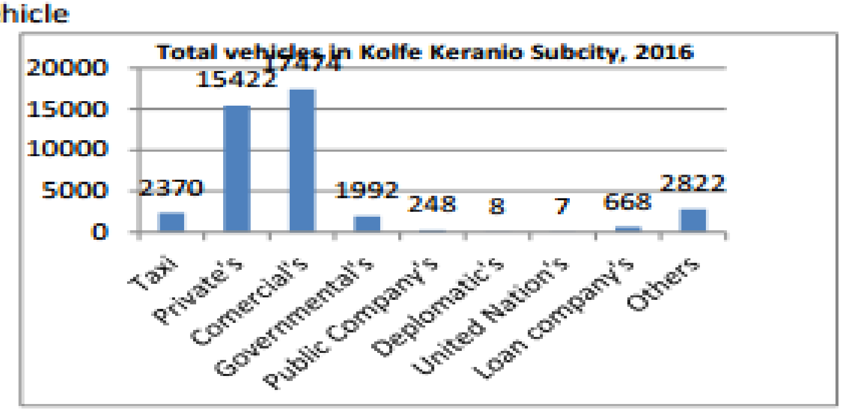
Gulele sub city

type of vehicle	Total No. Vehicle
Taxi	1889
Private's	7534
Comercial's	7152
Governmental's	1253
Public Company's	129
Deplomatic's	0
United Nation's	0
Loan company's	82
Others	237
Total	18276



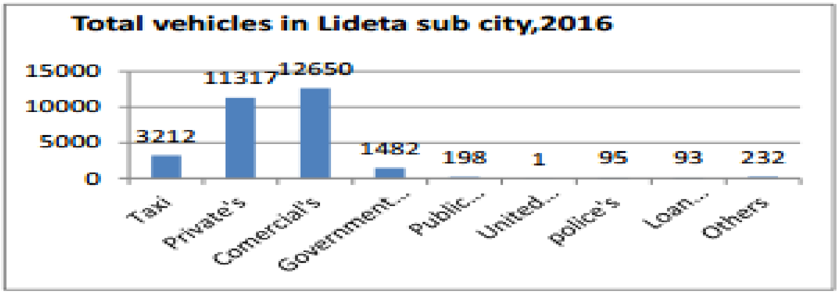
Kolfe sub city

type of vehicle	Total No. Vehicle
Taxi	2370
Private's	15422
Comercial's	17474
Governmental's	1992
Public Company's	248
Deplomatic's	8
United Nation's	7
Loan company's	668
Others	2822
Total	41011



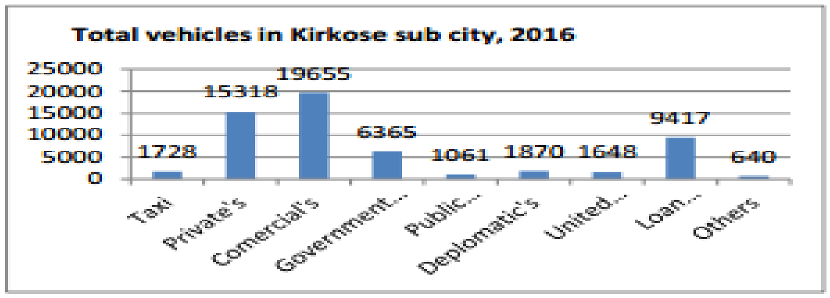
Lideta sub city

type of vehicle	Total No. Vehicle
Taxi	3212
Private's	11317
Comercial's	12650
Governmental's	1482
Public Company's	198
United Nation's	1
police's	95
Loan company's	93
Others	232
Total	29280



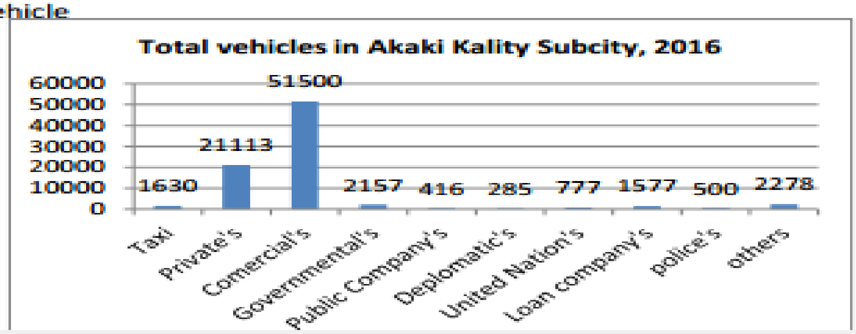
Kirkose sub city

type of vehicle	Total No. Vehicle
Taxi	1728
Private's	15318
Comercial's	19655
Governmental's	6365
Public Company's	1061
Deplomatic's	1870
United Nation's	1648
Loan company's	9417
Others	640
Total	57702



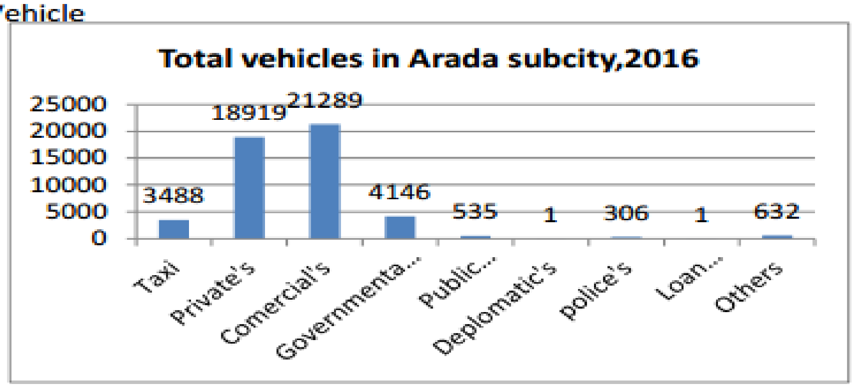
Akaki Kality sub city

type of vehicle	Total No. Vehicle
Taxi	1630
Private's	21113
Comercial's	51500
Governmental's	2157
Public Company's	416
Deplomatic's	285
United Nation's	777
Loan company's	1577
police's	500
others	2278
Total	82233



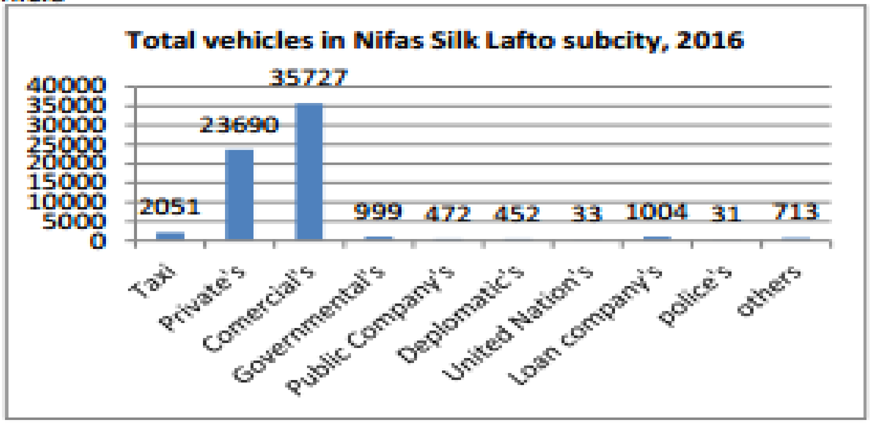
Arada sub city

type of vehicle	Total No. Vehicle
Taxi	3488
Private's	18919
Comercial's	21289
Governmental's	4146
Public Company's	535
Deplomatic's	1
police's	306
Loan company's	1
Others	632
Total	49317



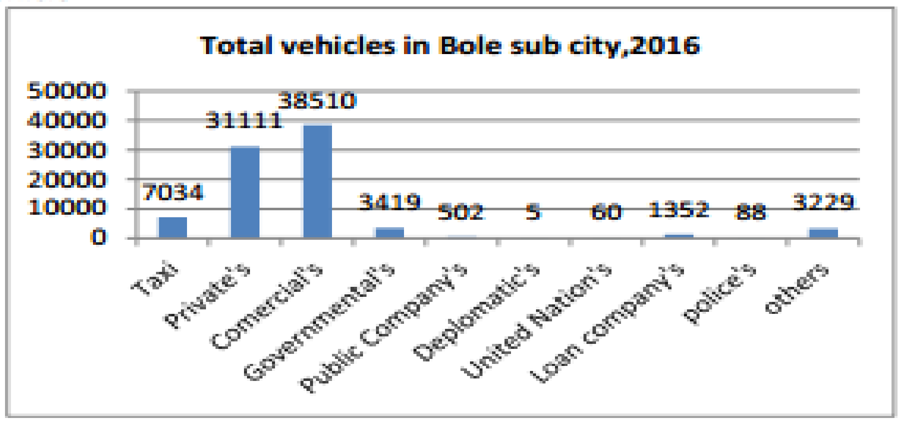
Nifas Silk sub city

type of vehicle	Total No. Vehicle
Taxi	2051
Private's	23690
Comercial's	35727
Governmental's	999
Public Company's	472
Deplomatic's	452
United Nation's	33
Loan company's	1004
police's	31
others	713
Total	65172



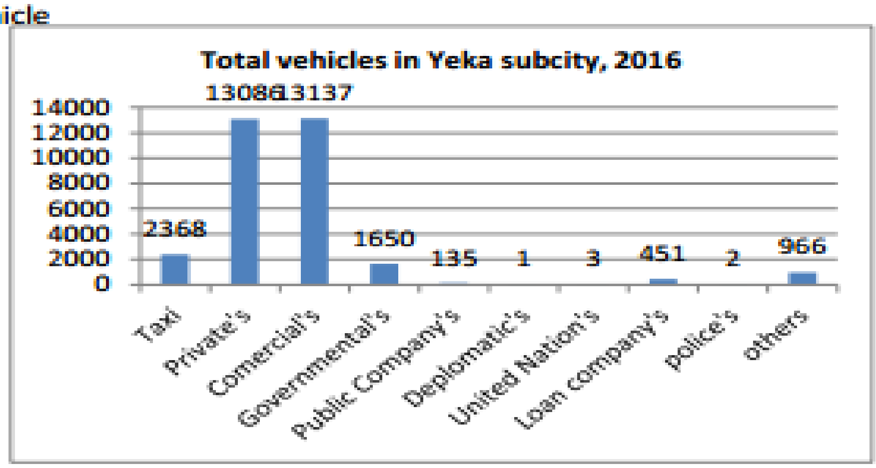
Bole sub city

type of vehicle	Total No. Vehicle
Taxi	7034
Private's	31111
Comercial's	38510
Governmental's	3419
Public Company's	502
Deplomatic's	5
United Nation's	60
Loan company's	1352
police's	88
others	3229
Total	85310

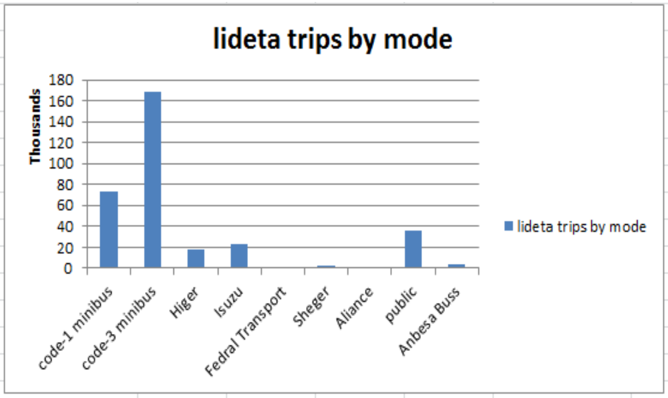


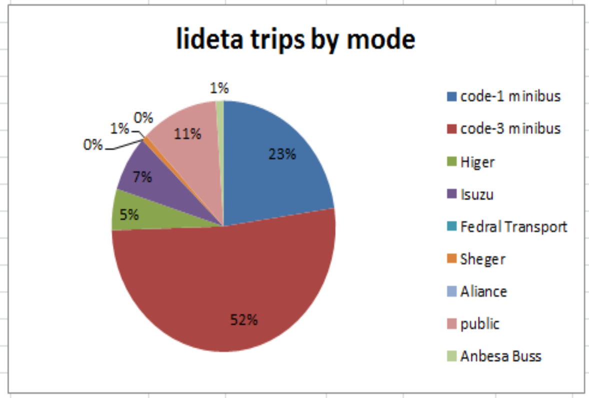
Yeka sub city

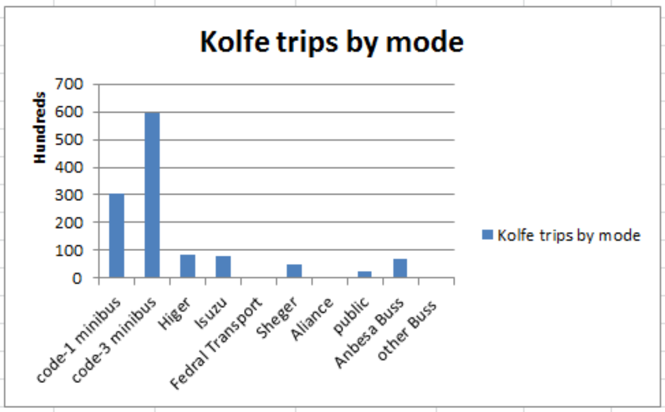
type of vehicle	Total No. Vehicle
Taxi	2368
Private's	13086
Comercial's	13137
Governmental's	1650
Public Company's	135
Deplomatic's	1
United Nation's	3
Loan company's	451
police's	2
others	966
Total	31799

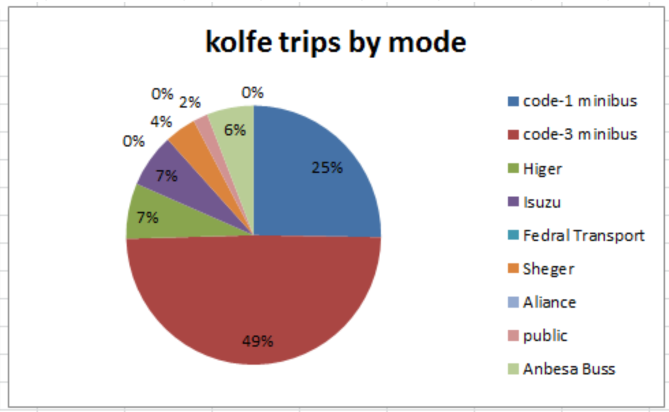


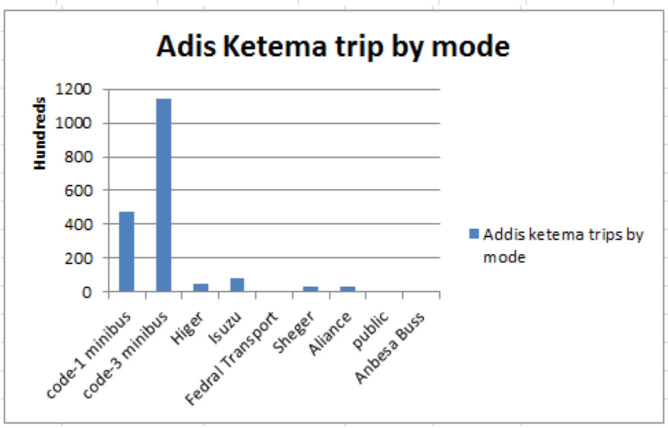
Appendix C Average daily trips by different public transport modes in Addis Ababa sub cities, 2017.

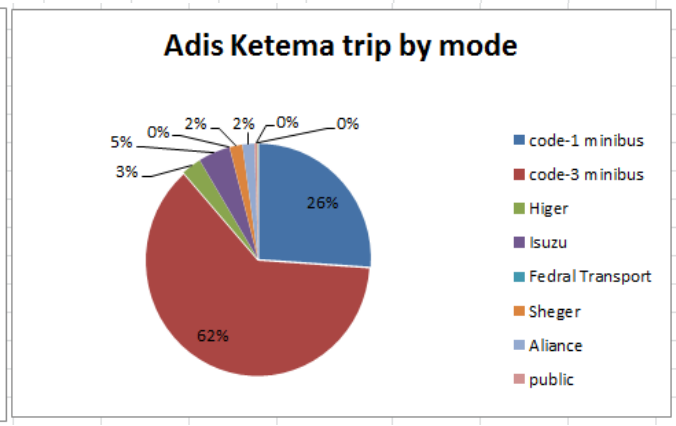


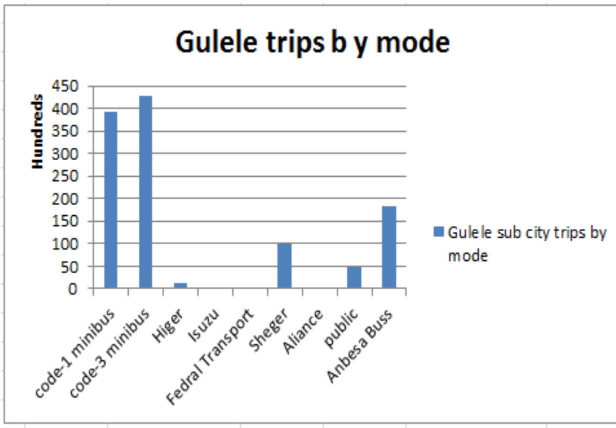


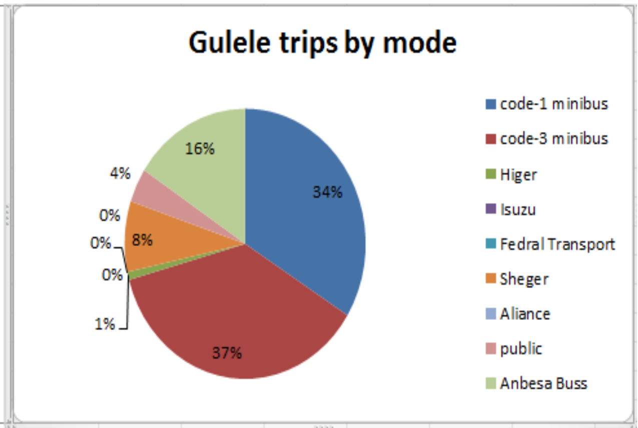


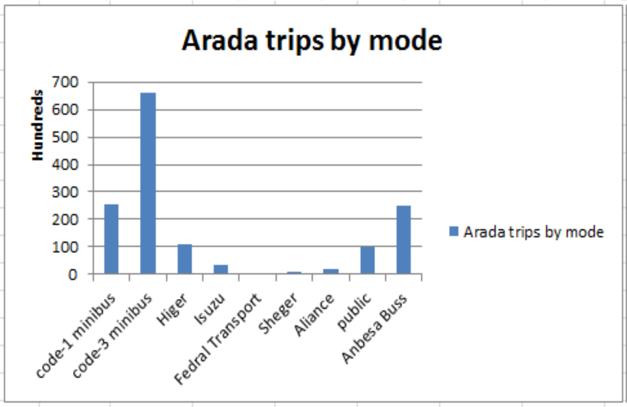


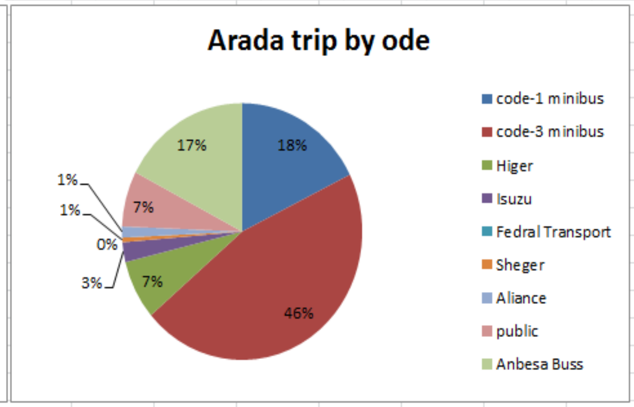


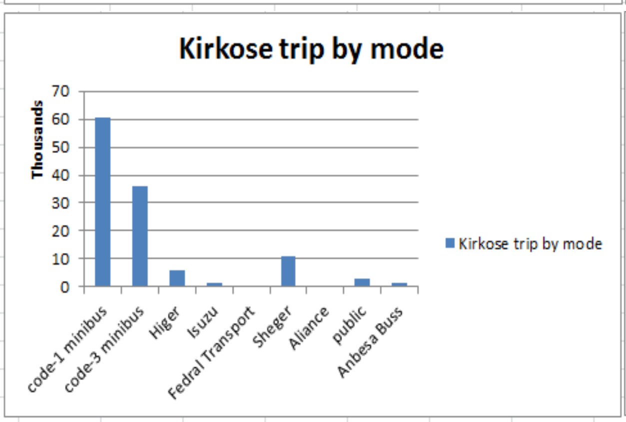


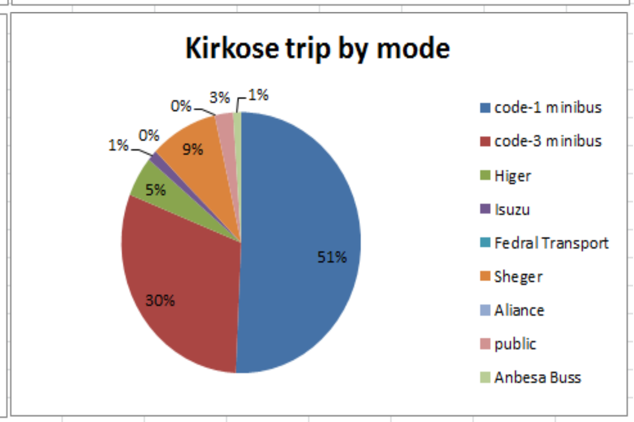

Gulele trips b y mode
Hundreds
450
400
350
300
250
200
150
100
50
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Gule le sub city trips by mode

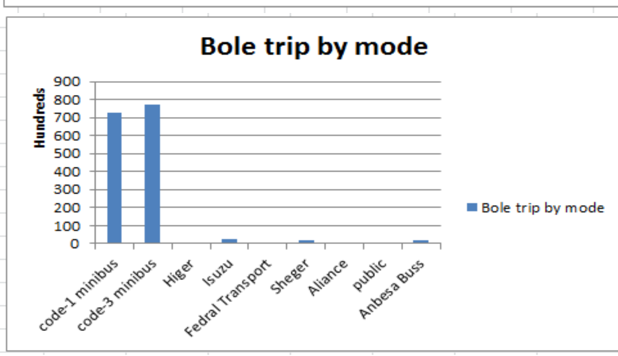

Gulele trips by mode
34%
37%
1%
0%
0%
8%
0%
4%
16%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss

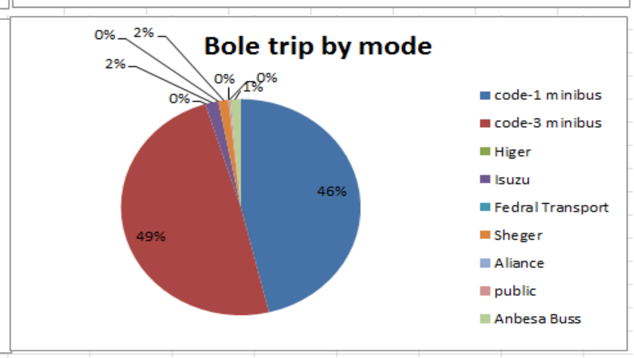

Arada trips by mode
Hundreds
700
600
500
400
300
200
100
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Arada trips by mode

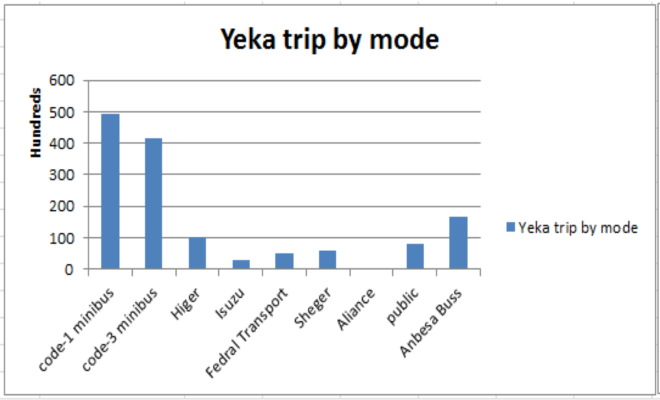

Arada trip by ode
18%
46%
7%
3%
0%
1%
1%
7%
17%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss

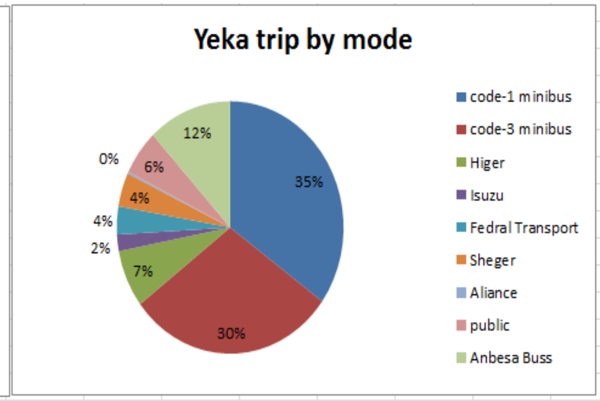

Kirkose trip by mode
Thousands
70
60
50
40
30
20
10
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Kirkose trip by mode

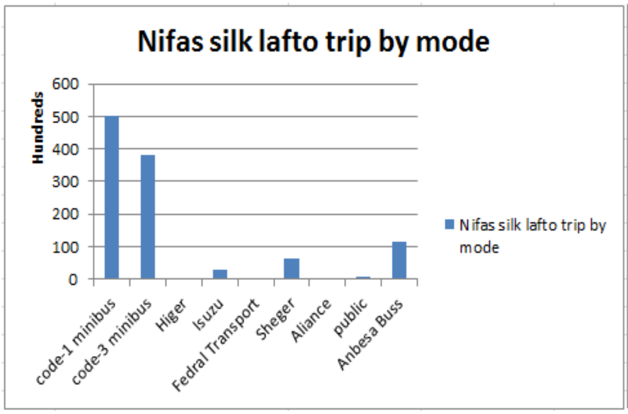

Kirkose trip by mode
51%
30%
5%
1%
0%
9%
0%
3%
1%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss

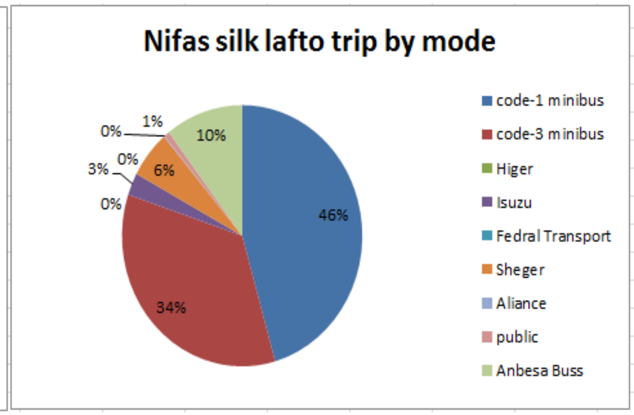

Bole trip by mode
Hundreds
900
800
700
600
500
400
300
200
100
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Bole trip by mode


Bole trip by mode
46%
49%
0%
2%
0%
2%
0%
1%
0%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss


Yeka trip by mode
Hundreds
600
500
400
300
200
100
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Yeka trip by mode


Yeka trip by mode
35%
30%
7%
2%
4%
4%
0%
6%
12%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss


Nifas silk lafto trip by mode
Hundreds
600
500
400
300
200
100
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Nifas silk lafto trip by mode


Nifas silk lafto trip by mode
46%
34%
0%
3%
0%
6%
0%
1%
10%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss

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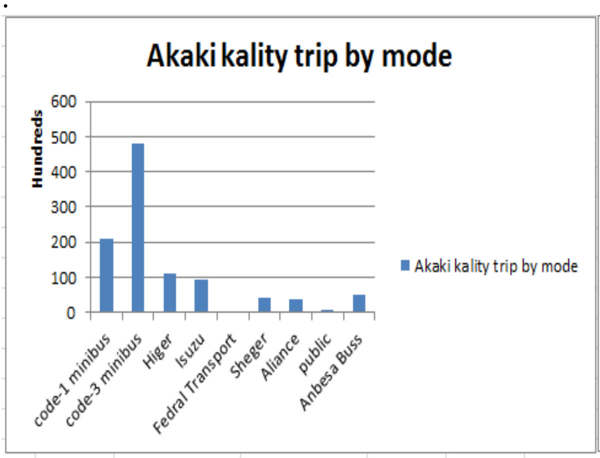
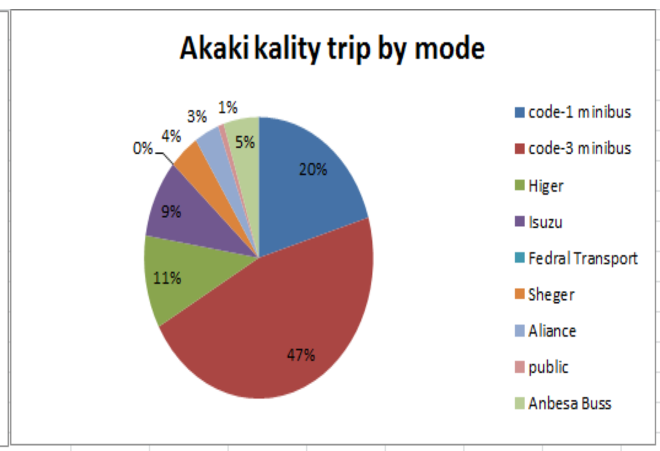

Akaki kality trip by mode
Hundreds
600
500
400
300
200
100
0
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss
Akaki kality trip by mode


Akaki kality trip by mode
20%
47%
11%
9%
0%
4%
3%
1%
5%
code-1 minibus
code-3 minibus
Higer
Isuzu
Fedral Transport
Sheger
Aliance
public
Anbesa Buss